MISCELLANEOUS PAPER EL-91-2

US Army Corps of Engineers

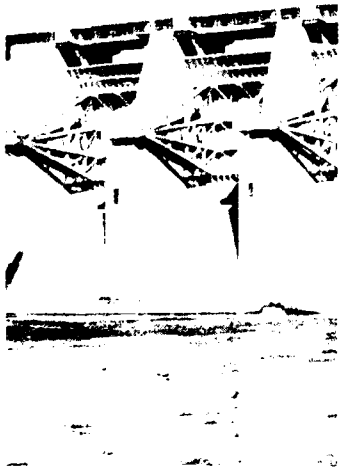
EFFECTS OF STORAGE ON SEDIMENT TOXICITY, BIOACCUMULATION POTENTIAL, AND CHEMISTRY

by

Henry E. Tatem, Dennis L. Brandon, Charles R. Lee,
A. Susan Jarvis, R. Glenn Rhett

Environmental Laboratory

DEPARTMENT OF THE ARMY
Waterways Experiment Station, Corps of Engineers
3909 Halls Ferry Road, Vicksburg, Mississippi 39180-6199



January 1991
Final Report

Prepared for US Army Engineer District, New York
New York, New York 10278-0090

ENVIRONMENTAL LABORATORY

Destroy this report when no longer needed. Do not return it to the originator.

The findings in this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.

The contents of this report are not to be used for advertising, publication, or promotional purposes. Citation of trade names does not constitute an official endorsement or approval of the use of such commercial products.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	January 1991	Final report

4. TITLE AND SUBTITLE

Effects of Storage on Sediment Toxicity, Bioaccumulation Potential, and Chemistry

5. FUNDING NUMBERS

6. AUTHOR(S)

Henry E. Tatem, Dennis L. Brandon, Charles R. Lee, A. Susan Jarvis, R. Glenn Rhett

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

USAE Waterways Experiment Station, Environmental Laboratory, 3909 Halls Ferry Road, Vicksburg, MS 39180-6199

8. PERFORMING ORGANIZATION REPORT NUMBER

Miscellaneous Paper EL-91-2

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

USAE District, New York
New York, NY 10278-0090

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

Available from National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

Current guidance on storage of sediments for bioassay/bioaccumulation tests requires that samples be held at 4° C and used within 2 weeks of collection. The objective of this study was to determine the effects of sediment storage for 40 weeks on sediment toxicity, bioaccumulation potential, and chemical analyses. Toxicity and bioaccumulation tests were conducted five times during 40 weeks of storage. Chemical analyses were performed three times during this period. The data indicate that sediments can be held for longer than 2 to 4 weeks, in many cases, without significant effect on test results. However, results of the study also show that tests performed at different times can produce different results.

This study showed that a sediment that was toxic to mysids remained toxic during 16 weeks of sediment storage. Two sediments that were toxic initially continued to show significant toxicity after 8 and 16 weeks of sediment storage.

(Continued)

14. SUBJECT TERMS	15. NUMBER OF PAGES
See reverse	62
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED		

13. (Concluded).

One sediment, not toxic initially or at 4 weeks, changed during storage, becoming significantly toxic compared to the Atlantic Ocean (Ref) sediment. The bioaccumulation results showed that certain sediment contaminants (lead, mercury, polychlorinated biphenyls, and some polycyclic aromatic hydrocarbons, PAHs), generally did not reveal a statistical change in bioaccumulation, relative to Ref animals, during 16 weeks of sediment storage. Other PAHs, including phenanthrene, anthracene, benzo(a)anthracene, and chrysene, did change in bioaccumulation potential during storage. Sediment chemistry data showed changes for some conventional parameters such as chemical oxygen demand, oil and grease, total Kjeldahl nitrogen, and ammonia nitrogen during storage.

14. (Concluded).

Bioaccumulation	Mercury	Polycyclic aromatic hydrocarbons
Bioassays	*Mysidopsis*	Sediment
Cadmium	*Nereis*	Sediment storage
Contaminants	Polychlorinated biphenyls	Sediment toxicity
Lead		

SUMMARY

Current US Army Corps of Engineers (CE) guidance on storage of sediments for bioassay/bioaccumulation tests requires that samples be held at 4° C and used within 2 weeks of collection. Using sediment samples within this relatively brief storage time can be difficult in cases where many samples are needed or where unknown contaminants may be present. Obtaining and testing sediments can be expensive, especially if multiple collection trips and/or chemical characterizations are necessary. The current guidance is not based on empirical data but on the practicality of obtaining sediment samples from one location and conducting specific sediment bioassays and other analyses. Neither the tiered testing approach nor the possibility that a chemical analysis or bioassay would need to be repeated was considered in developing the current guidance.

The objective of this study was to determine the effects of sediment storage at 4° C on sediment toxicity, bioaccumulation potential, and chemical analyses. Four sediments were obtained from New York Harbor waterways or the Atlantic Ocean (Ref), subjected to extensive chemical analyses, and tested with organisms used by the US Army Engineer District, New York. Test sediments were collected from Westchester Creek (WC), Gowanus Bay (GB), and Arthur Kill (AK) waterways.

Sediment toxicity tests using mysids *Mysidopsis bahia* and bioaccumulation tests using sandworms (*Nereis virens*) were conducted five times (initial or <2 weeks, and at 4, 8, 16, and 40 weeks of storage). Sediment chemical analyses were performed three times (initial or <2 weeks, and at 16 and 40 weeks). Chemical data for the reference sediment and the three contaminated sediments are presented. The bioassay and bioaccumulation data indicate that these sediments can be held for longer than 2 to 4 weeks, in many cases, without significant effect on the test results. However, the data also show that toxicity and bioaccumulation tests performed at different times can produce different results.

The *M. bahia* tests clearly showed WC sediment to be the most toxic and the Ref sediment to be the least toxic. The GB and AK sediments were intermediate in toxicity. These results were consistent for four test times: initial and 4, 8, and 16 weeks. At 40 weeks, however, the three contaminated sediments were less toxic when compared to previous test times. These results show that WC sediment can be held for 16 weeks without changing toxicity

potential, when compared statistically to Ref sediment. However, a similar analysis of the AK data showed that sediment changed in toxicity potential from initial testing to 4 weeks. Statistical comparisons for the two less toxic sediments, GB and AK, also showed they were not toxic after 4 weeks of storage but were so at 8 and 16 weeks. That is, toxicity increased during storage of 16 weeks, and decreased at 40 weeks.

Survival of *N. virens*, the bioaccumulation organism, was similar during the 40-week testing period for three of the four sediments. Approximately 90 percent of the sandworms survived at each of the five storage times in the GB, AK, and Ref sediments. One sediment, WC, was not toxic initially, but became toxic at the 16-week test time and remained toxic at 40 weeks. Survival was reduced to approximately 50 percent for the 16- and 40-week tests. Controls for each of the five tests were exposed to clean sand, and survival was 95 percent or greater each time.

Tissue analyses of sandworms for three metals (cadmium, Cd; lead, Pb; and mercury, Hg), polychlorinated biphenyls (PCBs), and selected polycyclic aromatic hydrocarbons (PAHs) indicated that the effects of storage on bioaccumulation were contaminant specific. Statistical analysis of the bioaccumulation data showed that Pb was more likely to be bioaccumulated from sediment than Cd or Hg, relative to the Ref sediment. The Pb results were generally consistent (animals exposed to test sediments GB and WC were shown to contain higher levels of Pb than Ref animals) through 16 weeks of storage. Tissue concentrations of Cd for *Nereis* exposed to the contaminated sediments were generally elevated in comparison to Ref sandworms, but the differences were not always statistically significant. Mercury was not accumulated by sandworms at any of the storage times. *Nereis* exposed to GB and WC sediments accumulated PCBs; results were significant for animals exposed to the GB sediment at all five test times.

Many of the PAHs were not accumulated by *Nereis*. Numerous values below the detection limit were found in the PAH data set. However, when specific PAHs, such as acenaphthene, fluoranthene, and pyrene, were bioaccumulated initially, they continued to be bioaccumulated by the sandworms at subsequent storage times, up to 40 weeks. Some PAHs (e.g., phenanthrene, anthracene, and chrysene) showed bioaccumulation at some test times but not at others.

Approximately 40 sediment parameters, including conventional parameters such as total organic carbon and chemical oxygen demand (COD), metals, PCBs, and PAHs, were measured at initial, 16, and 40 weeks of storage. Very few

parameters decreased significantly at both 16 and 40 weeks of storage. More parameters decreased after 40 weeks storage than after 16 weeks, compared to initial levels. Examples include COD and oil and grease (O & G). These two parameters decreased significantly at 40 weeks for all three test sediments. Total Kjeldahl nitrogen (TKN) and ammonia nitrogen (NH_3-N) generally increased in the sediments during storage. Metals such as Cd and Hg showed no significant decrease during 40 weeks of sediment storage. PCBs tended to decrease during storage, especially at the 16-week test time; however, there were cases in which PCBs at 40 weeks storage were significantly greater than at 16 weeks. Only 1 of the 16 PAHs that was monitored decreased significantly during storage. Napthalene decreased at 16 weeks in one of the three contaminated sediments.

This study showed that a sediment that was toxic to mysids (WC) remained toxic during 16 weeks of sediment storage. Two sediments that were toxic initially continued to show significant toxicity after 8 and 16 weeks of sediment storage. One sediment, not toxic initially or at 4 weeks, changed during storage, becoming significantly toxic compared to the Atlantic Ocean (Ref) sediment. The bioaccumulation results showed that certain sediment contaminants (Pb, Hg, PCBs, and some PAHs) generally did not reveal a statistical change in bioaccumulation, relative to Ref animals, during 16 weeks of sediment storage. Other PAHs, including phenanthrene, anthracene, benzo(a)anthracene, and chrysene, did change in bioaccumulation potential during storage. Sediment chemistry data showed changes for some conventional parameters such as COD, O & G, TKN, and NH_3-N during storage.

PREFACE

This investigation of storage effects on sediment tests was sponsored by the US Army Engineer District, New York. Work was conducted by the Environmental Laboratory (EL), US Army Engineer Waterways Experiment Station (WES), under the supervision of Dr. Lloyd H. Saunders, Chief of the Contaminant Mobility and Regulatory Criteria Group (CMRCG); Dr. Charles R. Lee, former Chief of the CMRCG; Mr. Donald L. Robey, Chief of the Ecosystem Research and Simulation Division (ERSD); and Dr. John Harrison, Chief of the EL. New York District project managers were Ms. Oksana Yaremko, Ms. Carol Coch, and Mr. John Tavolaro, Chief of the Water Quality Compliance Branch.

The study was conducted by Dr. Henry E. Tatem, with expert technical assistance from Ms. A. Susan Jarvis, Mr. R. Glenn Rhett, and Ms. Mary Anne Tweedle, all of the ERSD. Dr. Elizabeth Stafford and Ms. Carole Brown, ERSD, obtained the sediment samples. Dr. Eric Crecelius, Battelle Pacific Northwest Laboratories, Sequim, WA, coordinated chemical analyses of the sediment and tissue samples and provided the narrative on chemical methods. Mr. Dennis L. Brandon, ERSD, performed statistical analyses of the data.

COL Larry B. Fulton, EN, was Commander and Director of WES. Dr. Robert W. Whalin was Technical Director.

This report should be cited as follows:

Tatem, Henry E., Brandon, Dennis L., Lee, Charles R., Jarvis, A. Susan, and Rhett, R. Glenn. 1991. "Effects of Storage on Sediment Toxicity, Bioaccumulation Potential, and Chemistry," Miscellaneous Paper EL-91-2, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

CONTENTS

EFFECTS OF STORAGE ON SEDIMENT TOXICITY, BIOACCUMULATION POTENTIAL, AND CHEMISTRY

PART I: INTRODUCTION

1. Current US Army Corps of Engineers (CE) guidance on storage of sediments for bioassay testing states that sediments should (a) never be frozen or allowed to dry and (b) be stored at 4° C and used within 2 to 4 weeks of collection (US Environmental Protection Agency/US Army Corps of Engineers (USEPA/USACE) 1978; US Army Engineer District (USAED), New York 1984) (also, New York District Standard Operating Procedure*). This relatively brief storage time can be a problem for CE Districts and their contractors because of the many tasks that must be accomplished between the time of sediment collection and the beginning of bioassay and bioaccumulation tests. For example, sediments must be homogenized and subsampled for physical and chemical analyses prior to biological testing. Test animals must be obtained and acclimated to the laboratory and/or test conditions. The health of the test animals must also be verified prior to testing.

2. A tiered testing approach, where sediments are analyzed chemically and/or subjected to rapid toxicity assessment prior to additional tests (Engler et al. 1988), requires that sediments be held for a period of weeks, at least, while initial tests are completed and evaluated. When sediments are suspected or known to be highly contaminated, additional time may be required for safety considerations prior to beginning work. It is not surprising, therefore, that CE Districts and their contractors, after investing time and funds in collecting, holding, and preparing sediment samples and organisms for testing, are faced with situations where all of the required bioassays and bioaccumulation tests have not been started within 2 to 4 weeks of sediment collection.

3. Relatively few sediment toxicity methods have been published, and only a few of these specifically discuss sediment holding times and conditions prior to testing. Nebeker et al. (1984) discuss methods and review sediment toxicity studies, but do not specifically address the sediment storage

---

* Personal Communication, 1989, John Tavolaro, US Army Engineer District, New York; New York, NY.

question. Prater and Hoke (1980), Bahnick et al. (1981), Malueg et al. (1984), and LeBlanc and Surprenant (1985) have examined the toxicity of various freshwater sediments. Other investigators (Dillon 1983, Swartz et al. 1985, Clark et al. 1987, Plesha et al. 1988, Tatem 1988) have studied the toxicity of marine sediments. Storage times, however, have not been consistent. Sediments have been tested within 2 days (Burton and Stemmer 1988), 5 days (Swartz et al. 1985), 7 days (Malueg et al. 1984), or 2 weeks (Nebeker et al. 1984).

4. In a study of a copper-spiked sediment, Malueg, Schuytema, and Krawczyk (1986) found that freezing of sediments at -20° C reduced toxicity to *Daphnia magna*, while sediments stored at 5° C tended to increase in toxicity after 8 and 12 weeks of storage and then to decrease at 17 and 25 weeks storage. Tests were conducted on sediment stored for 0, 1, 3, 8, 12, 17, and 25 weeks. These results were for a laboratory-spiked sediment and may not apply to naturally contaminated sediment containing a variety of contaminants.

5. Dillon (1983) examined a marine sediment stored at -22°, 4°, and 25° C and tested at 0, 2, 4, 7, 12, and 20 weeks of storage. Percent mortality for mysids (*Mysidopsis bahia*) exposed to sediment stored at 4° C ranged from 55 to 100 percent during a 20-week storage period. A trend of increasing toxicity became significant after 4 weeks storage. The sediment toxicity appeared to decrease between 12 and 20 weeks storage but remained greater than that found after 0 and 2 weeks of storage. Reference toxicant data for mysids in the 20-week test indicated that the mysids were stronger that animals used in previous tests. This suggests that sediment toxicity may not have decreased at 20 weeks. Toxicity results for sediments stored at 25° C varied over time compared to sediment stored at 4° C; sediments stored at -22° C were also variable, but after 20 weeks were similar in toxicity to sediments stored 0 weeks (Dillon 1983).

6. A recent study of the effects of storage at 4° C on four contaminated marine sediments (Tatem 1988) indicated that two sediments remained nontoxic during a 28-week storage period while two other more contaminated sediments retained their toxicity during the 28-week period. Other studies (Dillon 1983; Malueg, Schuytema, and Krawczyk 1986) indicate that sediments stored at 4° or 5° C can retain their toxicity and may become more toxic during storage.

7. Previous sediment storage experiments have not combined extensive chemical analyses with biological testing and have not tested sediments held

for periods longer than 28 weeks. Another factor that has not been fully evaluated is the potential influence of different classes of contaminants on the toxicity of stored sediments. A sediment contaminated mainly with polycyclic aromatic hydrocarbons (PAHs) may require testing within 4 weeks, while a metal or polychlorinated biphenyl (PCB)-contaminated sediment could be tested, with consistent results, after storage of 8 weeks or longer. Sediment parameters such as total volatile solids, chemical oxygen demand, and total organic carbon have not been evaluated in conjunction with biological tests to show whether sediments change chemically or biologically during storage.

8. This report presents results from five mysid sediment toxicity tests and five *Nereis virens* sediment bioaccumulation tests completed at <2 (initial), 4, 8, 16, and 40 weeks of storage. Sediment samples were analyzed for chemical parameters after <2 (initial), 16, and 40 weeks of storage. The objective was to determine the effects of various storage times (at 4° C) on sediment toxicity, bioaccumulation potential, and chemistry. Extensive chemical analyses for one representative marine reference sediment and three representative contaminated sediments are presented. This information will allow CE Districts, or anyone planning a sediment study, some flexibility in how much sediment can be obtained during a single sampling trip and the overall conduct of the study. This information is important in relation to sediment tiered testing assessments and in decisions concerning whether to repeat a bioassay or bioaccumulation assessment, using stored sediment. Data from this study will also be of interest to individuals and governmental agencies interested in archiving sediment samples for later chemical analyses or biological tests.

PART II: MATERIALS AND METHODS

Sediment Collection

9. Four sites were sampled using a clamshell dredge. The first collection site, located approximately 5 miles (8 km) off Sandy Hook, NJ, in the Atlantic Ocean, contained clean study material and was used as the reference (Ref) sediment (Figure 1). Three other sites, suspected of containing contaminated sediment, were Westchester Creek (WC), Gowanus Bay (GB), and Arthur Kill (AK), all located in shipping channels in the New York/New Jersey Harbor complex. At each site the clamshell dredge removed three or four grabs (approximately 25 gal (95 dm^3) of sediment per grab) and deposited the material on the deck of the collection vessel. Sediment was shoveled into fourteen 5-gal (19-dm^3) high-density polyethylene containers. Containers were completely filled with the wet sediment, sealed, and placed in a refrigerated truck (4° C) as soon as the vessel returned to the dock each day. Collection of the sediments took 3 days. All containers were transported by refrigerated truck to the US Army Engineer Waterways Experiment Station in Vicksburg, MS, and placed in a room at 4° C.

10. Within 2 days of their arrival, sediments from each of the four sites were homogenized using a mechanical sediment mixer. Sediment from the 14 containers was emptied into the mixer, mixed for approximately 30 min, and returned sequentially to the containers to ensure homogeneity. The sealed containers were placed in the cold room. Within 5 days of their arrival at the laboratory, 3 of 14 containers, for each sediment, were removed from the cold room and used to prepare sediment suspended particulate (Plumb 1981) for the mysid tests and sediment aquaria for the *Nereis* bioaccumulation tests. Sediment samples from the same three containers were also taken at this time for chemical analyses. Sediment removed from the cold room for a test was used up each time. Other undisturbed containers of mixed sediment were used after 4, 8, 16, and 40 weeks of storage.

Study Design

11. Sediments were tested for toxicity and bioaccumulation potential at five storage times (initial or <2, 4, 8, 16, and 40 weeks). Initial toxicity

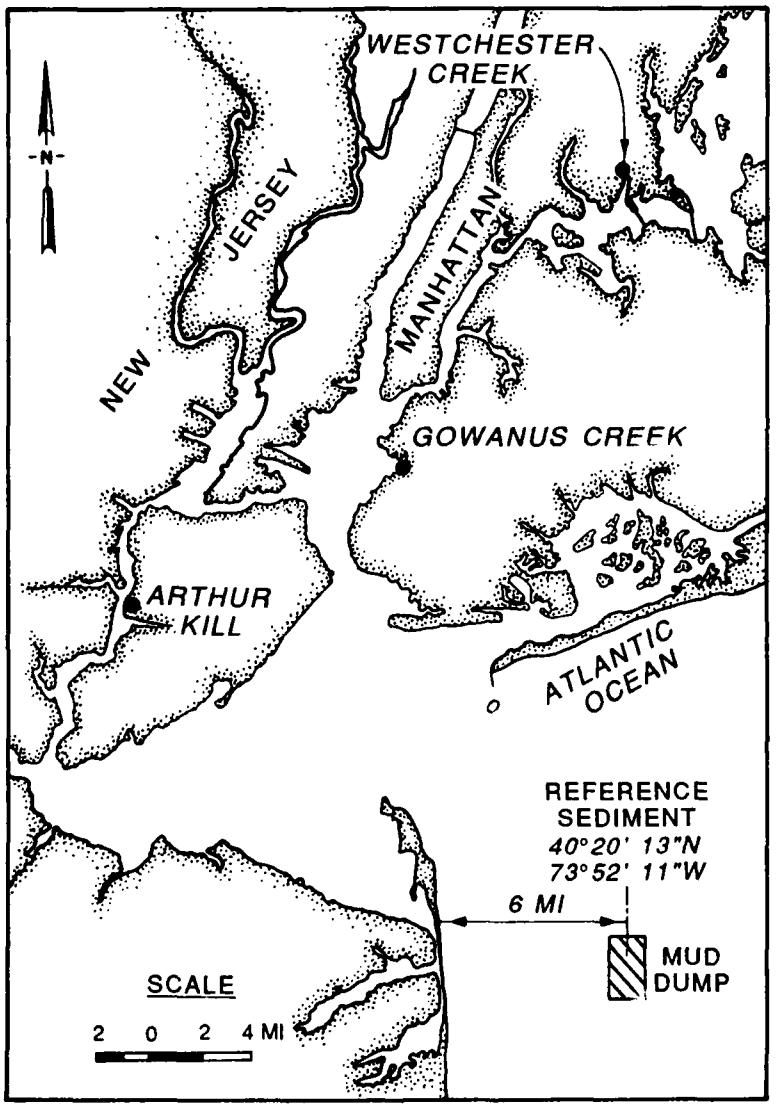


Figure 1. New York area sediment collection sites (to convert miles (US statute) to kilometers, multiply by 1.609347)

tests were started approximately 8 days after the first sediments were collected; bioaccumulation tests were started the next day. Sediments were characterized physically (particle-size analyses) and chemically, initially (<2) and after 16 and 40 weeks of storage. Initial sediment chemical analyses included all USEPA priority pollutants. Subsequent sediment and tissue analyses focused on contaminants identified in the initial analyses and those of greatest interest to the New York District, i.e., metals (including cadmium, Cd; mercury, Hg; and lead, Pb), total PCBs, and selected PAHs. Mysids were exposed to the sediments and/or sediment suspended particulate material (SPM) for 7 days (toxicity tests). *Nereis* were exposed to the sediments for 10 days in the bioaccumulation tests. Test conditions, such as sediment contact and exposure times, represented worst-case conditions so that initial effects would be measurable and could be compared with later test results. Both toxicity and bioaccumulation tests were static, with water replacement for bioaccumulation tests, i.e. 25 percent replacement every 48 hr. Test animals were exposed directly to the Ref or contaminated sediments and were obtained from commercial suppliers. Toxicity bioassays were conducted according to protocols used for a previous sediment toxicity study (Tatem 1988).

12. Procedures for the bioaccumulation tests were similar to existing New York District bioaccumulation protocols (USAED, New York 1984) except for one change, the elimination of a layer of Ref sediment below the test sediment in the aquaria. This change prevented the animals from avoiding the test material by borrowing into the Ref material.

Mysidopsis bahia Toxicity Experiments

13. Mysid shrimp were exposed in 2-ℓ beakers containing a 1- to 2-cm layer of deposited sediment covered with liquid SPM. This material is the same as unfiltered sediment elutriate water (Plumb 1981; USAED, New York 1984). The animals were exposed to the SPM and sediment for 48 hr and then held and observed for 5 additional days in beakers containing SPM without the sediment layer (Tatem 1988). Controls were held in 2-ℓ beakers that contained no sediment. Test salinity was 30 ppt; temperature was 20° ± 1° C. Ten mysids were placed in each of five replicate beakers for each treatment. Static exposure to deposited sediment and SPM for 48 hr represented a worst-case exposure condition. The mysids could not be counted in beakers containing sediment. They were removed from these beakers and placed in beakers

containing SPM only and counted. Data at 120 hr, representing 48 hr of direct exposure to sediment and SPM plus 3 days exposure to SPM only, were chosen for deciding whether sediment toxicity changed during storage. The mysids were used only for the determination of sediment toxicity.

Nereis virens Bioaccumulation Experiments

14. The sandworms (*N. virens*) were exposed using 10-gal (38-dm^3) aquaria containing 6 to 7 cm of deposited sediment. Four aquaria for each of the sediments contained sediment, artificial seawater (salinity = 30 ppt), and 20 *Nereis* (approximately 40 g of wet tissue). Gentle aeration that did not disturb the sediment layer was provided to each aquarium. Animals were fed tropical fish food daily. Four control aquaria contained clean sand, artificial seawater, and 20 sandworms. Test temperature was 20° ± 1° C. Animals were exposed for 10 days. After the exposure period, mortality was recorded; survivors were held for 24 hr in sediment-free water in small aquaria prior to being frozen for chemical analyses.

Sediment and Tissue Chemical Analyses

15. Sediment and tissue analyses were coordinated with Dr. Eric Crecelius, Battelle Pacific Northwest Laboratories, Sequim, WA, and conducted according to the methods described below.

Sediment analyses

16. Methods used for sediment analyses were as follows:

a. Freeze-dried and ground sediment samples were analyzed by energy-dispersive X-ray fluorescence for aluminum, arsenic, chromium, copper, iron, manganese, nickel, lead, selenium, and zinc (Nielson and Sanders 1983). Other metals were analyzed by atomic absorption (AA) after the sediment was totally dissolved in a mixture of nitric, perchloric, and hydrofluoric acids at elevated temperature (130° C) in a sealed Teflon container. Mercury was quantified by cold vapor AA; the other metals (silver, beryllium, cadmium, antimony, and thallium) were quantified by Zeeman graphite furnace AA with matrix modifiers.

b. Sediments were analyzed for PAHs and phthalates using USEPA Method 625, which indicates solvent extraction, column cleanup, and quantification by gas chromatography (GC)/mass spectrophotometry. The PCBs and DDT were analyzed by USEPA Method 8080 and quantified by GC-electron capture detector.

c. The Standard Method 503 (American Public Health Association (APHA) 1985) procedure was used for analysis of oil and grease. Sediment was extracted with freon and quantified by infrared absorption.

d. Grain size was determined by measuring the mass of material collected on sieves and the mass of material that settled in a 1-ℓ graduated cylinder at specific time periods (Plumb 1981).

e. Total solids and total volatile solids were determined by the methods of Plumb (1981), which include dry weight at 130° C followed by ashing at 550° C.

f. Total organic carbon in sediment was determined using a nondispersive infrared measurement of carbon dioxide released from the organic carbon during combustion according to Standard Method 505 (APHA 1985). Inorganic carbonates were released from the sediment sample before combustion using hydrochloride.

g. Chemical oxygen demand was determined by Standard Method 509 A (APHA 1985).

h. Total phosphorus was determined by Standard Method 424 F (APHA 1985).

i. Total Kjeldahl nitrogen samples were digested with sulfuric acid and copper sulfate potassium catalyst, distilled into standard acid and titrated.

j. Sediments were extracted for ammonia with deionized water and analyzed directly (without filtration) by USEPA Method 350.3, specific ion electrode.

Tissue analyses

17. Methods used for tissue analyses were as follows:

a. Tissue samples for metals were homogenized with a Tissuemiser. An aliquot was freeze dried and digested with nitric and perchloric acid at 130° C in a sealed Teflon container. The digestates were analyzed for Hg by cold vapor AA; other metals were quantified by Zeeman graphite furnace AA.

b. Homogenized tissue was analyzed for PAHs and PCBs by GC-flame ionization detector and GC-ECD, respectively, after solvent extraction and a high-pressure liquid chromatography cleanup procedure developed by Krahn et al. (1988).

Statistical Analyses

18. The toxicity, bioaccumulation, and sediment concentration data were statistically analyzed using Cochran's test, parametric and nonparametric analysis of variance (ANOVA), the Waller-Duncan k-ratio t-test, the one-tailed t-test, and the Mann-Whitney U-test. In each case, Cochran's test was used to evaluate the homogeneous variance assumption. This assumption was made when the parametric ANOVA was used. In instances where this assumption was

violated, the nonparametric ANOVA was used. For the parametric ANOVA, values for sediment concentrations, mysid survival, and *Nereis* survival or bioaccumulation were used. The nonparametric ANOVA used ranks based on tissue concentrations or animal survival data. Mean values were compared in two ways. The first comparison allowed the evaluation of each site over time (e.g., <2, 4, 8, 16, and/or 40 weeks). The second comparison evaluated means from four sites at each sampling period. In both cases, equality between the means was the null hypothesis. The alternate hypothesis was the assumption that at least one mean was different from the others.

19. The Waller-Duncan k-ratio t-test was used with the parametric and nonparametric ANOVA to identify means that were statistically different. One exception was the sediment samples from the reference site. Replicate reference sediment samples were analyzed initially (<2) and at week 16 only. Therefore, the Waller-Duncan k-ratio t-test was not applicable, and the Mann-Whitney U-test was used. One-tailed t-tests were used to evaluate the bioaccumulation results from GB, WC, and the Ref site. Statistical comparisons used "less than" (detection limit) data according to Porter, Ward, and Bell (1988); i.e., values less than the detection limit were set equal to the detection limit. Interpretation of the results, however, was not attempted when many or all of the values in a data set were less than the detection limits.

20. Common log and natural log transformations were used to achieve homogeneous variance with some parameters. In each case, the ANOVA and Waller-Duncan k-ratio t-tests were applied to the transformed data. Cochran's test and the Mann-Whitney U-test are described in Winer (1971) and Sokal and Rohlf (1981), respectively. The Waller-Duncan k-ratio t-test and the one-tailed t-test are described in Steel and Torrie (1980). Each test was conducted at the 0.05 level of significance.

PART III: RESULTS AND DISCUSSION

Mysid Toxicity Data

21. Mysids exposed to the Ref sediment showed greater than 80 or 90 percent survival after 120 hr except at 16 weeks (Figure 2 and Table 1). Control survival at 16 weeks was also low. Table A1 (Appendix A) presents additional mysid data plus information on statistical methods. Survival of mysids exposed to WC sediment was significantly less than survival of Ref-exposed animals at all five test times. Results of the statistical analyses show that although WC was always more toxic than the Ref sediment, WC was most toxic at 8 and 16 weeks and significantly less toxic at 40 weeks (Table 1).

22. Mysids exposed to AK and GB sediments demonstrated an intermediate toxicity response, showing mean survival values generally greater than WC but less than Ref. These two sediments were toxic, in relation to the Ref sediment, at 8 and 16 weeks, but not at 4 weeks. Thus, they did change during storage (Table 1). Survival of mysids exposed to AK sediment ranged from 86 percent at 4 weeks to 34 percent at 16 weeks (Figure 2).

23. Previous studies of the effects of storage of naturally contaminated sediments on toxicity include Dillon (1983) and Tatem (1988). Dillon found that toxicity tended to increase over time (up to 12 weeks of storage) and then to decrease at 20 weeks. A similar trend was observed in the present study. The three contaminated sediments were more toxic at 8 and 16 weeks compared to the initial and 4-week storage times. Toxicity decreased at 40 weeks storage. Tatem (1988) showed that heavily contaminated sediments retained toxicity after 28 weeks of storage. The results from this study show that the WC sediment, shown to be toxic during the initial test, was still significantly toxic at later test times. Results for GB and AK sediments, however, were different at different times. Malueg, Schuytema, and Krawczyk (1986), using a copper-spiked sediment, also found that sediment toxicity tended to increase during storage of 8 and 12 weeks and then to decrease after 17 and 25 weeks. Results from this study show that a clearly toxic sediment (WC) remained toxic during storage but that less toxic sediments such as AK and GB may change.

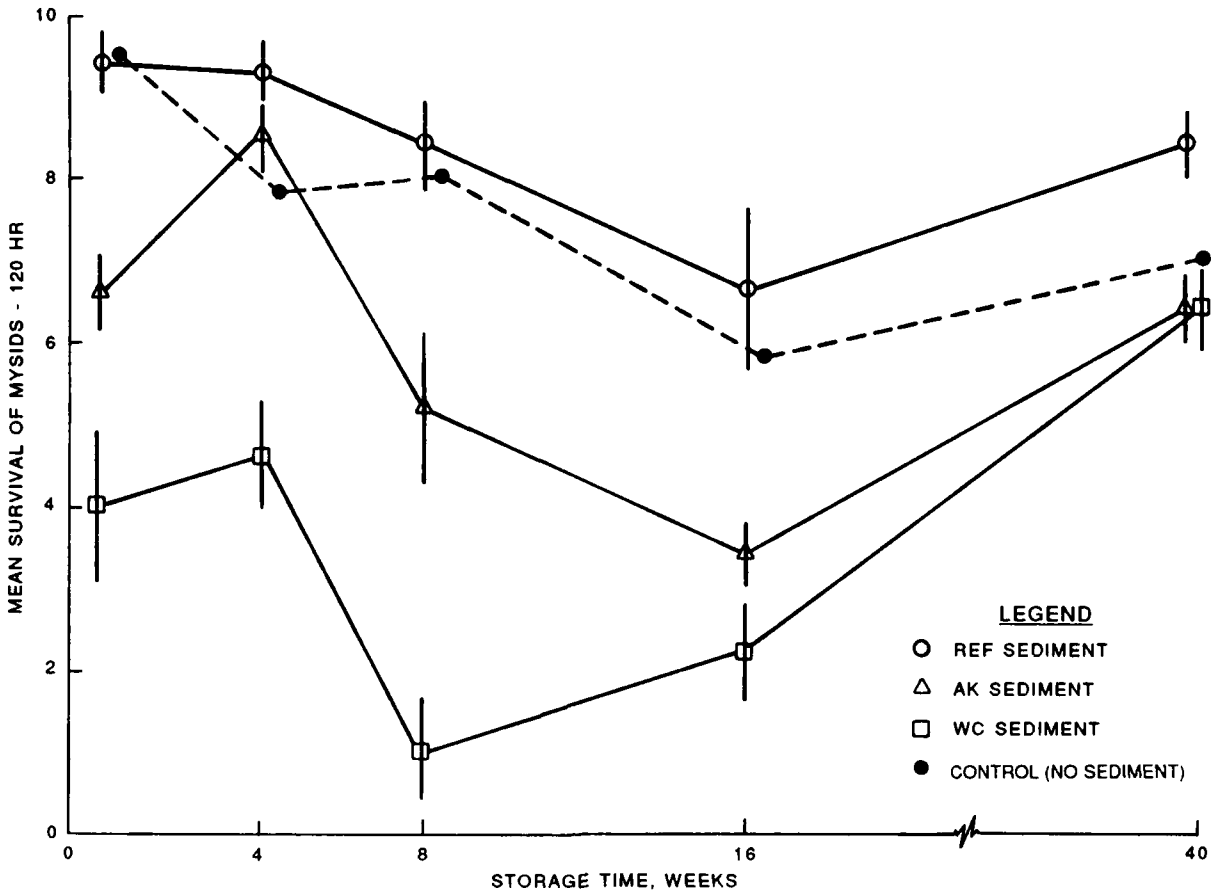


Figure 2. Mean survival of *M. bahia* exposed to Ref or contaminated sediment for 120 hr

Nereis Toxicity Data

24. Survival data for sandworms show that three sediments (Ref, GB, and AK) did not change in toxicity potential during storage (Tables 2 and A2 and Figure 3). The WC sediment was not toxic up to 8 weeks, but became toxic at 16 weeks of storage and remained so at 40 weeks. These large marine polychaetes are generally expected to survive a 10-day exposure to contaminated sediment (USEPA/USACE 1978) in order that survivors can be used to determine bioaccumulation potential. It is interesting that the sandworms showed the potential toxicity of the WC sediment, after 8 weeks of storage, and that this sediment was also found to be the most toxic to the mysids. Identification of specific parameters that cause sediment toxicity when sediments contain multiple contaminants is difficult. Since *Nereis* were used primarily to determine sediment bioaccumulation potential and not to assess sediment toxicity, these

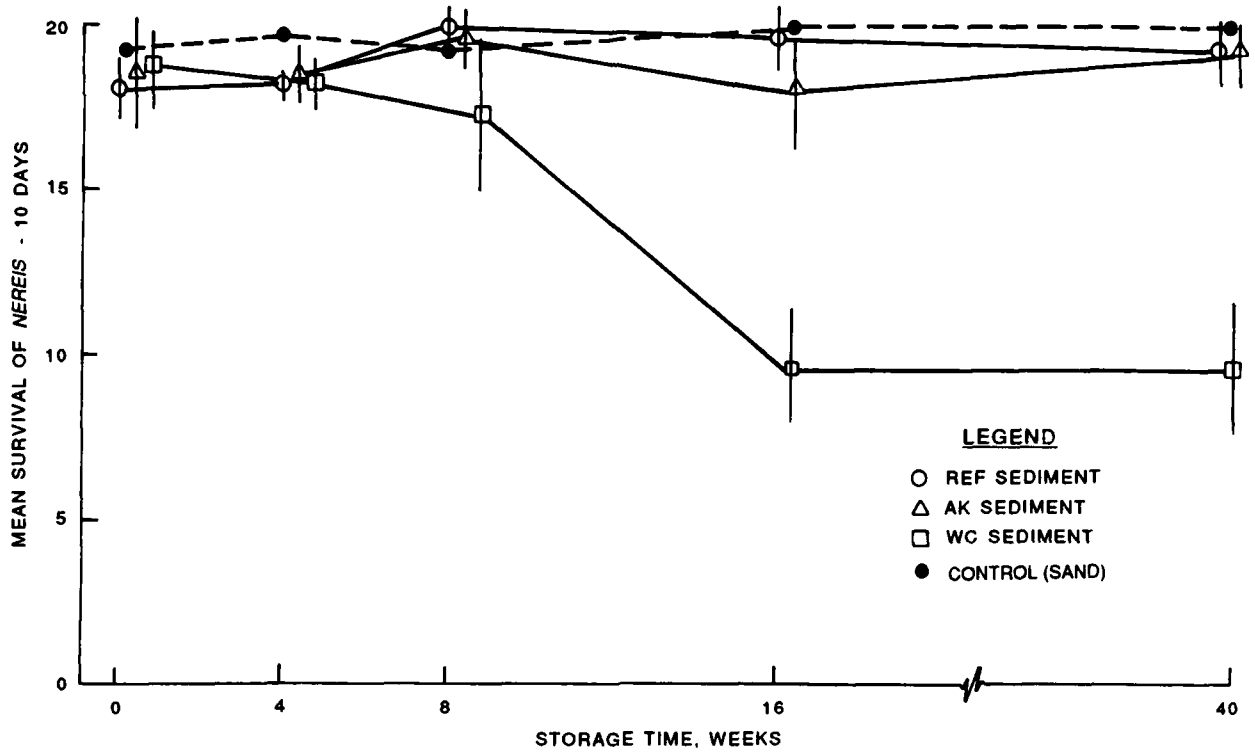


Figure 3. Mean survival of *N. virens* exposed to Ref or contaminated sediment for 10 days

toxicity data should not be used in place of the mysid data to determine acceptable sediment storage times.

Nereis Bioaccumulation Data

25. *Nereis* bioaccumulation data are presented in Tables 3 and A3. Tissue concentrations are shown for animals exposed to three sediments and for background (Bk) sandworms. Animals exposed to the AK sediment were not analyzed for tissue contaminants. The Bk animals were taken for analysis at the beginning of each of the five tests. These data can be used to indicate whether a statistical difference in bioaccumulation values should be considered biologically meaningful. For example, the Bk data showed that *Nereis* contained detectable levels of Cd, Pb, and Hg prior to exposure to the sediments. Comparison of Bk data to Ref data showed that animals exposed to the Ref sediment were generally less contaminated. There were cases in this data set in which statistical analyses indicated that animals exposed to one of the tests sediments accumulated a contaminant, yet the tissue concentration was within the background range. These cases were considered less important than

cases in which there was a statistical indication of bioaccumulation and the tissue concentration was greater than the background range.

Cadmium

26. The Cd data show that animals exposed to two contaminated sediments bioaccumulated Cd initially (at WC) and at 16 and 40 weeks (at GB). The tissue concentrations, however, were only slightly greater than the Ref values and generally fell within the Bk range. There was no clear indication of Cd bioaccumulation for either sediment. The Cd data, therefore, reveal a different bioaccumulation decision after the initial time for one sediment (WC) and after 16 weeks for the other (GB).

Lead

27. The Pb data indicate that Pb was bioaccumulated by the sandworms initially and at 4, 8, 16, and 40 weeks (Table 3 and Figure 4). The data at 4 weeks showed the highest concentrations of Pb in the tissues of both GB and WC animals; however, the Bk and Ref levels were also high. No statistical difference at 4 weeks for GB animals was found. These data showed that Pb was accumulated from two sediments but that storage affected the results. The bioaccumulation result for Pb is that one sediment (GB) changed after the initial time while the other (WC) did not change during 40 weeks of storage.

Mercury

28. Neither WC- nor GB-exposed sandworms contained significantly more Hg than Ref animals after the 10-day bioaccumulation test (Table 3). The data showed that *Nereis* exposed to the Ref and contaminated sediments generally contained less Hg than Bk animals. Tissue concentrations of WC and GB animals were never significantly greater than concentrations of Ref *Nereis*.

Polychlorinated biphenyls

29. Data for PCBs (total) showed that background animals contained PCBs and that bioaccumulation occurred for both WC and GB sandworms initially and at 8 weeks (Table 3 and Figure 5). Statistically significant bioaccumulation occurred for GB animals at every test period. Sediment chemical analyses (Tables 4-6) indicated that the GB sediment was higher in PCBs than the WC sediment. These data showed that the GB sediment, stored for 40 weeks, did not change in bioaccumulation potential but that the WC sediment did, after the initial storage time.

Polycyclic aromatic hydrocarbons

30. The PAH data set (Tables 3 and A3) contains numerous values less than the detection limit. Much of the data for the low molecular weight PAHs

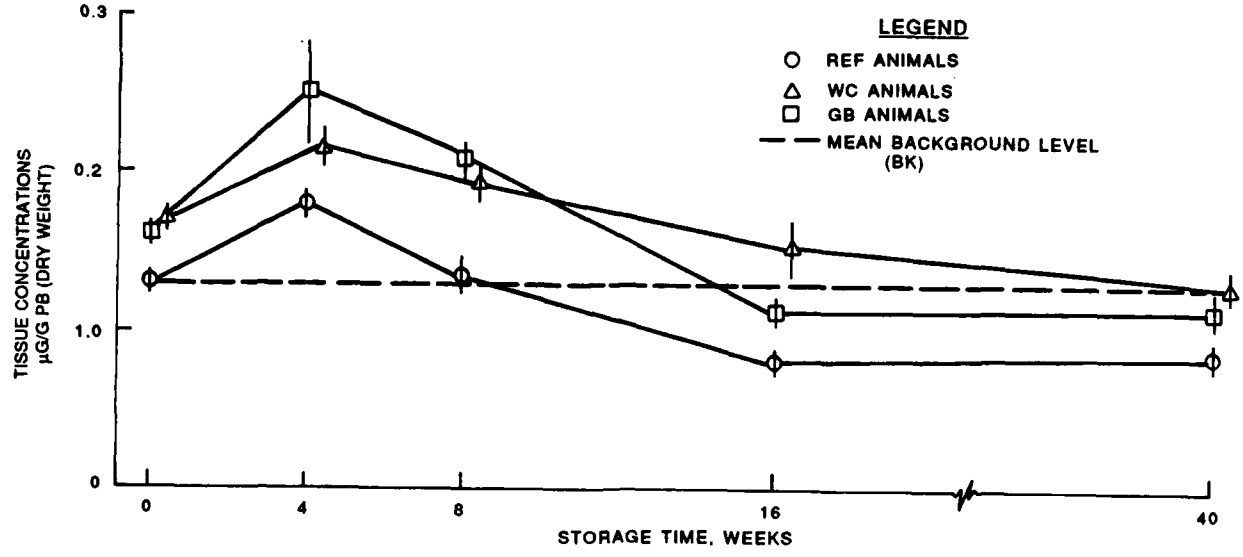


Figure 4. Bioaccumulation of Pb by *N. virens* exposed to Ref or contaminated sediment for 10 days

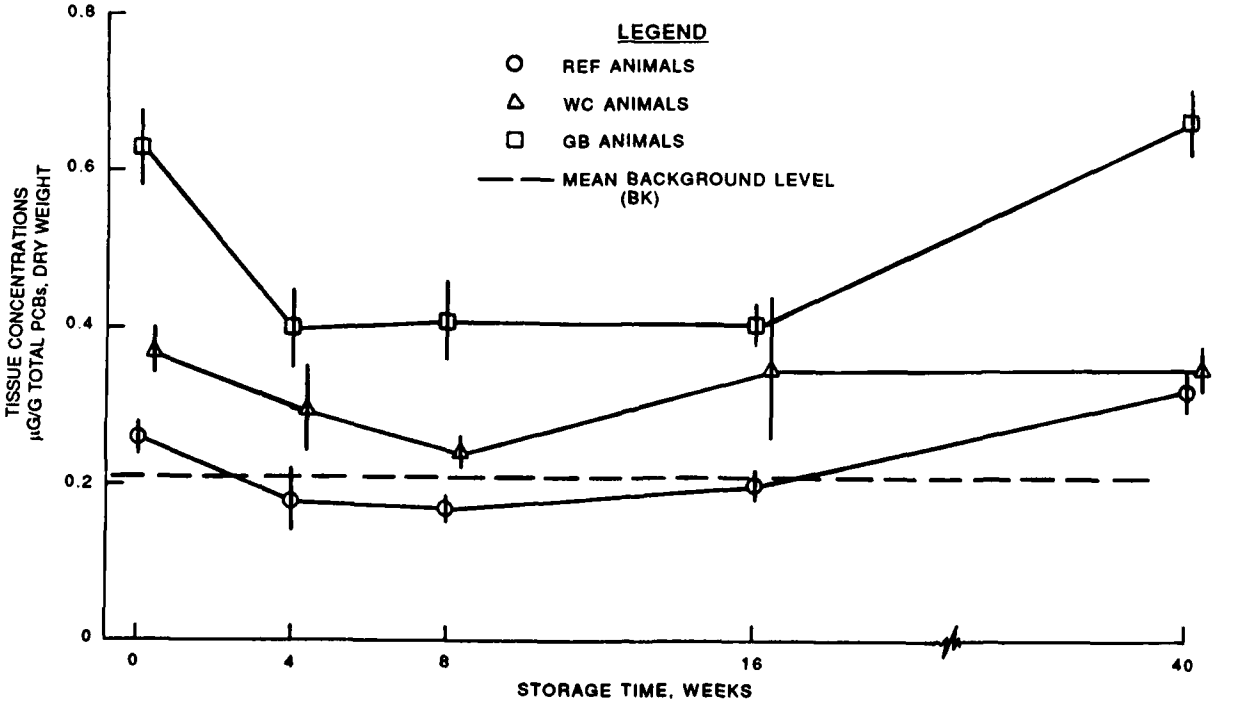


Figure 5. Bioaccumulation of PCBs by *N. virens* exposed to Ref or contaminated sediment for 10 days

(2- and 3-ring compounds such as naphthalene and phenanthrene) were at <0.1 μg/g levels in the *Nereis* tissues for both background and sediment-exposed animals. The possible biological effects of these tissue concentrations are unknown (Clarke and Gibson 1987). Each PAH is different physically and chemically, making generalizations difficult. The data showed that certain PAHs, such as 2-methylnaphthalene and fluorene, were not accumulated from the test sediments while others, fluoranthene and pyrene, for example, were. The following discussion examines the PAH data by grouping similar PAHs when possible.

31. Naphthalene, 2-methylnaphthalene, and acenaphthylene. Naphthalene (naphtha), 2-methylnaphthalene (2MNapht), and acenaphthylene (acenaphy) were not bioaccumulated; i.e., tissue concentrations for *Nereis* exposed to GB and WC sediments were not significantly higher than Ref tissue concentrations (Table 3). Most of the data were below detection limits. The data at 16 weeks for two of these PAHs that were above detection limits were not found to be statistically significant. These data indicate that 40 weeks storage did not result in a change in bioaccumulation potential.

32. Acenaphthene and fluorene. Data for acenaphthene (acenaph) showed bioaccumulation for GB-exposed animals at all storage times (Table 3). Bioaccumulation was clearly demonstrated because GB-exposed animals contained significantly greater concentrations of acenaph compared to Ref-exposed animals, and the data were higher than all of the Bk data. All acenaph values for WC-exposed *Nereis*, however, were less than detection limits. Thus, for both sediments there was no change in bioaccumulation potential during 40 weeks of storage. The fluorene data also showed no evidence of bioaccumulation. All GB and WC data were either less than detection limits or not significantly different from Ref. These data, then, indicate that 40 weeks storage did not result in a change in bioaccumulation potential.

33. Phenanthrene and anthracene. Animals exposed to the GB sediment accumulated phenanthrene (phenan) at 40 weeks (Table 3). The WC data for phenanthrene did not show bioaccumulation at any time. The conclusion for phenanthrene is that sediment GB could be stored for 16 weeks without changing the bioaccumulation result. WC sediment stored for 40 weeks did not change. The anthracene (anthra) data showed bioaccumulation for GB animals at 4 weeks. Bioaccumulation was not shown for WC animals. These data indicate that the GB sediment changed in bioaccumulation potential after the initial storage

period. The phenanthrene and anthracene data set was the first of the PAH data sets in which most of the values were greater than detection limits.

34. Fluoranthene, pyrene, and benzo(a)anthracene. The fluoranthene (fluoran) and pyrene data sets clearly demonstrate bioaccumulation initially and at subsequent test times (Table 3 and Figure 6). Animals exposed to the two test sediments accumulated significantly greater levels of these PAHs than animals exposed to Ref sediment in 15 of a possible 20 comparisons. Many of the tissue concentrations of fluoran and pyrene exceed 0.5 μg/g, while background data were generally less than 0.1 μg/g.

35. The fluoranthene data indicated that storage for 40 weeks (GB) or 4 weeks (WC) would not produce a different bioaccumulation result. The pyrene data revealed a change in bioaccumulation, for WC sediment, after the initial storage period. Data for benzo(a)anthracene (benzoaan) indicated that bioaccumulation potential changed during storage. This data set was characterized by numerous "less than" values, and there was no obvious pattern. Significant differences was demonstrated for WC-exposed animals at 4 weeks; results for GB-exposed animals showed no uptake until 40 weeks. The benzo(a)anthracene

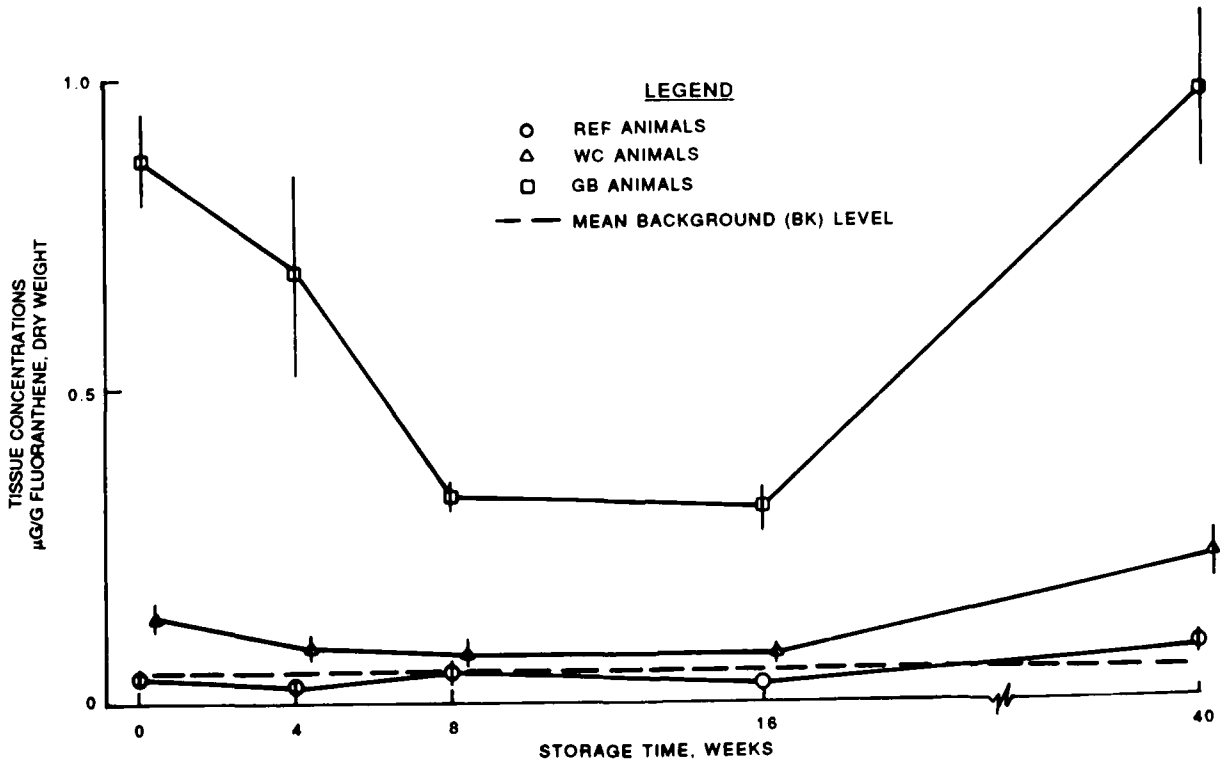


Figure 6. Bioaccumulation of fluoranthene by *N. virens* exposed to Ref or contaminated sediment for 10 days

results, therefore, do not suggest a definite conclusion, but show that one sediment changed after the initial test.

36. Chrysene, benzo(b)fluoranthene, and benzo(k)fluoranthene. The chrysene data for GB showed significant bioaccumulation initially and 4 weeks (Table 3). The WC data, however, revealed different bioaccumulation results after the initial test. The overall conclusion for chrysene is that bioaccumulation changed during storage. Results for GB-exposed animals showed that benzo(b)fluoranthene (benzobfl) was bioaccumulated at 40 weeks. Benzo(k)fluoranthene (benzokfl) also revealed bioaccumulation at 40 weeks. For both compounds, bioaccumulation was shown for GB-exposed animals but not for WC-exposed animals. Thus, 16 weeks of storage had no effect on bioaccumulation of these two PAHs.

37. Benzo(a)pyrene, indeno(123cd)pyrene, dibenzo(ah)anthracene, and benzo(ghi)perylene. The last four PAHs in Table 3 (benzoap, indeno123, dibenzah, and benzoghi) revealed no significant differences at any of the test times. These data, then, indicate that a similar bioaccumulation result would be found at any of the five storage periods.

38. The tabulation on the following page summarizes the bioaccumulation results based on data from Table 3. The X's indicate how long sediments GB and WC can be stored without changing a finding of bioaccumulation relative to the Ref sediment for each specific contaminant.

	Initial	4	8	16	40	Week*
Metal						
Cd	X(WC)			X(GB)		2
Pb	X(GB)				X(WC)	2
Hg					X(GB/WC)	40
PCBs (total)	X(WC)				X(GB)	2
PAHs						
Naphtha					X(GB/WC)	40
2-MNaptha					X(GB/WC)	40
Acenaphy					X(GB/WC)	40
Acenaph					X(GB/WC)	40
Fluoren					X(GB/WC)	40
Phenan				X(GB)	X(WC)	16
Anthra	X(GB)				X(WC)	2
Fluoran		X(WC)			X(GB)	4
Pyrene	X(WC)		X(GB)			2
Benzoaan	X(WC)			X(GB)		2
Chrysen	X(WC)	X(GB)				2
Benzobfl				X(GB)	X(WC)	16
Benzokfl				X(GB)	X(WC)	16
Benzoap					X(GB/WC)	40
Indenol23					X(GB/WC)	40
Dibenzah					X(GB/WC)	40
Benzoghi					X(GB/WC)	40

* Overall conclusion (test period prior to a statistical change in bioaccumulation). There were many cases in which bioaccumulation changed at 4 weeks for one sediment but did not change until 16 or 40 weeks for the other sediment. The overall conclusion in these cases was that bioaccumulation could change after 2 weeks of storage.

Sediment Chemistry Data

39. Sediment chemistry data include seven conventional parameters, 13 metals, DDTs, PCBs, 16 PAHs, and one phthalate. Tables 4-6 show chemical analysis data initially (Table 4) and at 16 (Table 5) and 40 (Table 6) weeks of storage. Statistical comparisons over time, for individual sediment parameters, are shown in Tables 7-10. Most of the changes shown in Table 7 occurred at 40 weeks. For example, percent total organic carbon (TOC), for GB sediment, was significantly lower at 40 weeks compared to initial and 16 weeks. The TOC and total volatile solids (TVS) did not change during 40 weeks storage of WC sediment.

40. The conventional parameters most likely to decrease during storage were oil and grease (O & G), chemical oxygen demand (COD), and total phosphorus (TP). Parameters most likely to increase during storage were total Kjeldahl nitrogen (TKN) and ammonia nitrogen (NH_3-N). Figures 7 and 8 show sediment chemistry results for COD and NH_3-N. The changes in sediment chemistry over time should not be used, without additional data, to determine how long a sediment can be stored. Bioassay data are required to support the sediment chemistry data. A lower COD value generally indicates a less toxic sediment, but higher NH_3-N values would tend to increase toxicity. After 40 weeks storage at 4° C the test sediments (WC, GB, and AK) remained one or two orders of magnitude higher in key parameters such as TVS, O & G, and COD than the Ref sediment. Only one parameter (COD) revealed a consistent (i.e., significantly lower values at 16 and 40 weeks) decrease during the study period yet still was much greater than the Ref sediment after 40 weeks of storage (Table 7).

41. The results of metals analyses are shown in Table 8. The sediment Cd data are plotted against storage time in Figure 9. Numerous significant changes were found; however, there were only two cases of significant decreases at both 16 and 40 weeks (Mn in WC sediment and Sb in GB sediment). Many of the changes were not large and would not be expected to result in different biological test results. For example, Hg in WC sediment initially was 2.4 ppm and at 40 weeks storage was 2.7 ppm, which was significantly higher. Lead in WC sediment was 328.7 ppm initially and 314.0 ppm at 40 weeks storage, which was significantly lower. These data show that important sediment contaminants such as Cd, Hg, and Pb may change during 40 weeks of storage but remain much greater than Ref sediment concentrations.

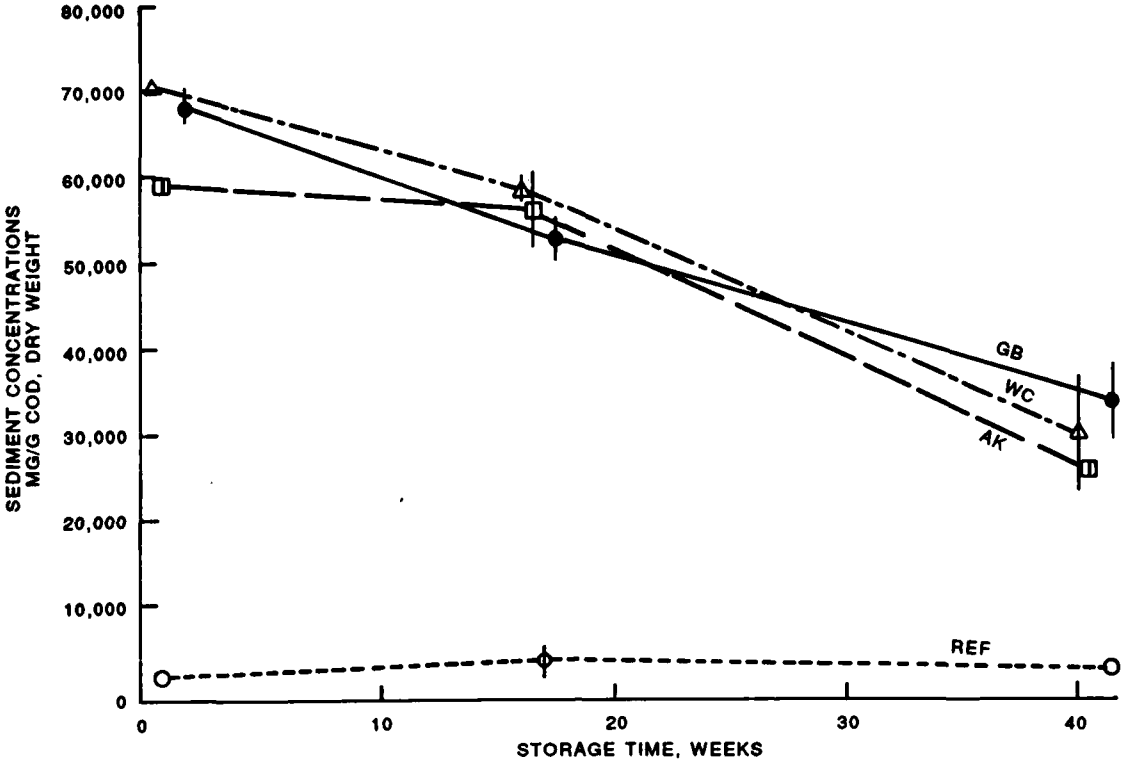


Figure 7. Results of sediment analyses for COD (initial and at 16 and 40 weeks)

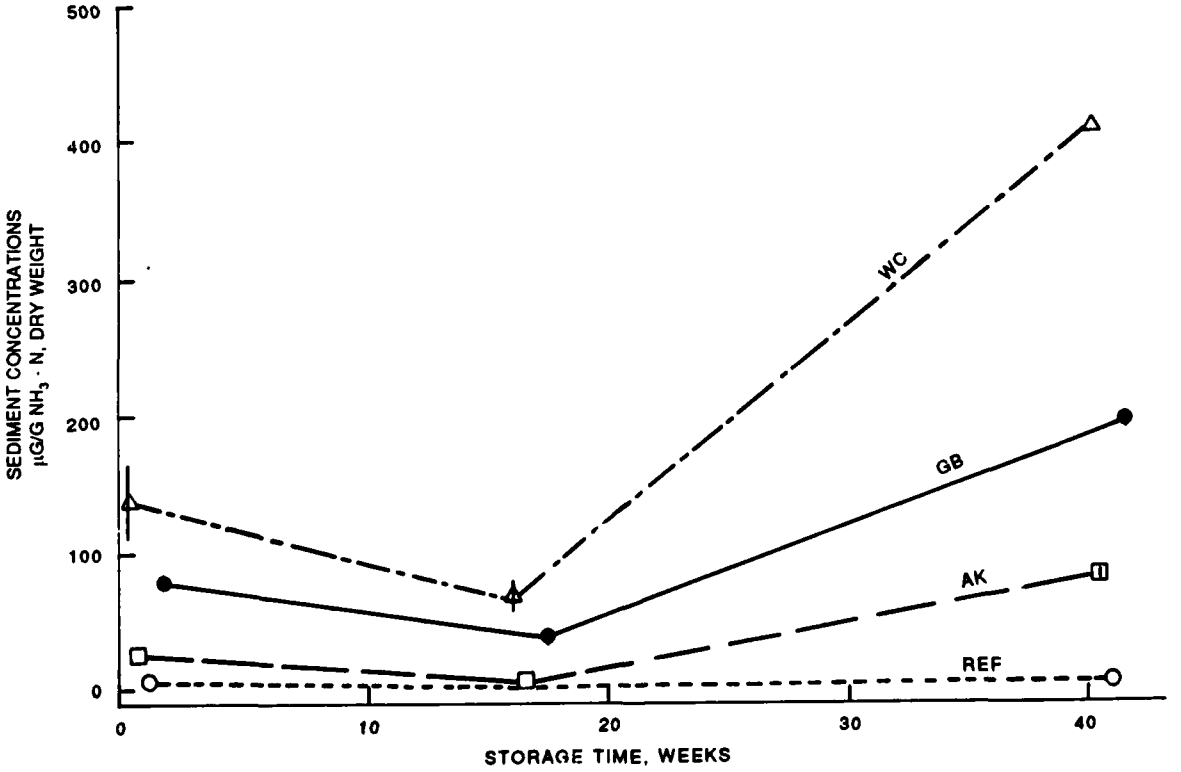


Figure 8. Results of sediment analyses for NH_3-N (initial and at 16 and 40 weeks

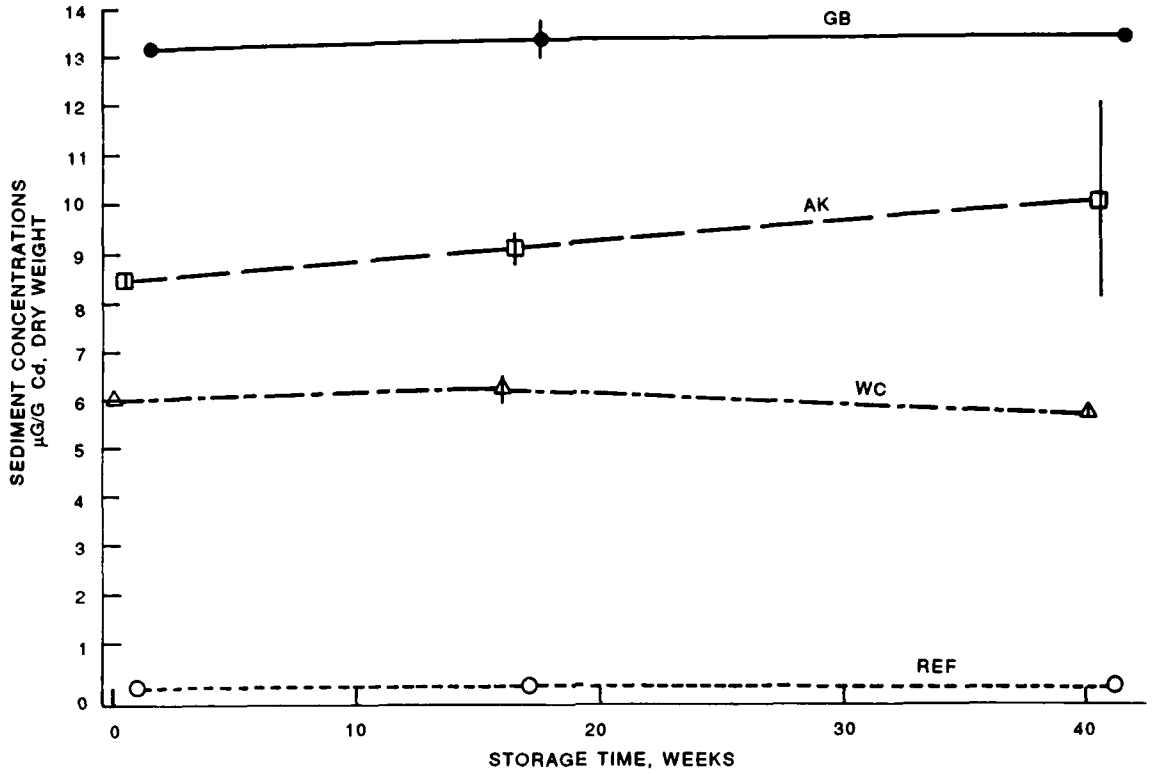


Figure 9. Results of sediment analyses for Cd (initial and at 16 and 40 weeks)

42. The PCB and DDT comparisons are shown in Table 9. Since the AK sediment contained DDT initially and the other two test sediments did not, the DDT data are shown only for AK and Ref sediments. PCBs in all of the sediments, except the Ref, were lower at 16 weeks storage. PCB 1254 was present in all of the test sediments; after 40 weeks storage, the sediment PCB concentrations were usually less than half the initial concentrations (Figure 10). These sediments were not heavily contaminated with PCBs. Detection limits were high due to the PAHs in these sediments. Thus, some of the changes seen could have been due to normal laboratory variation for analyses conducted at different times. This hypothesis is supported by the fact that most of the data at 16 weeks were uniformly lower than the initial PCB data, but at 40 weeks, PCBs were higher than at 16 weeks. The DDT data show a pattern similar to the PCBs where initial results appeared higher than at 16 weeks but not at 40 weeks.

43. The PAH data (Table 10 and Figures 11 and 12) are generally consistent for all of the sediments. These contaminants were present at higher concentrations than the PCBs. Some are known to be volatile but did not decrease

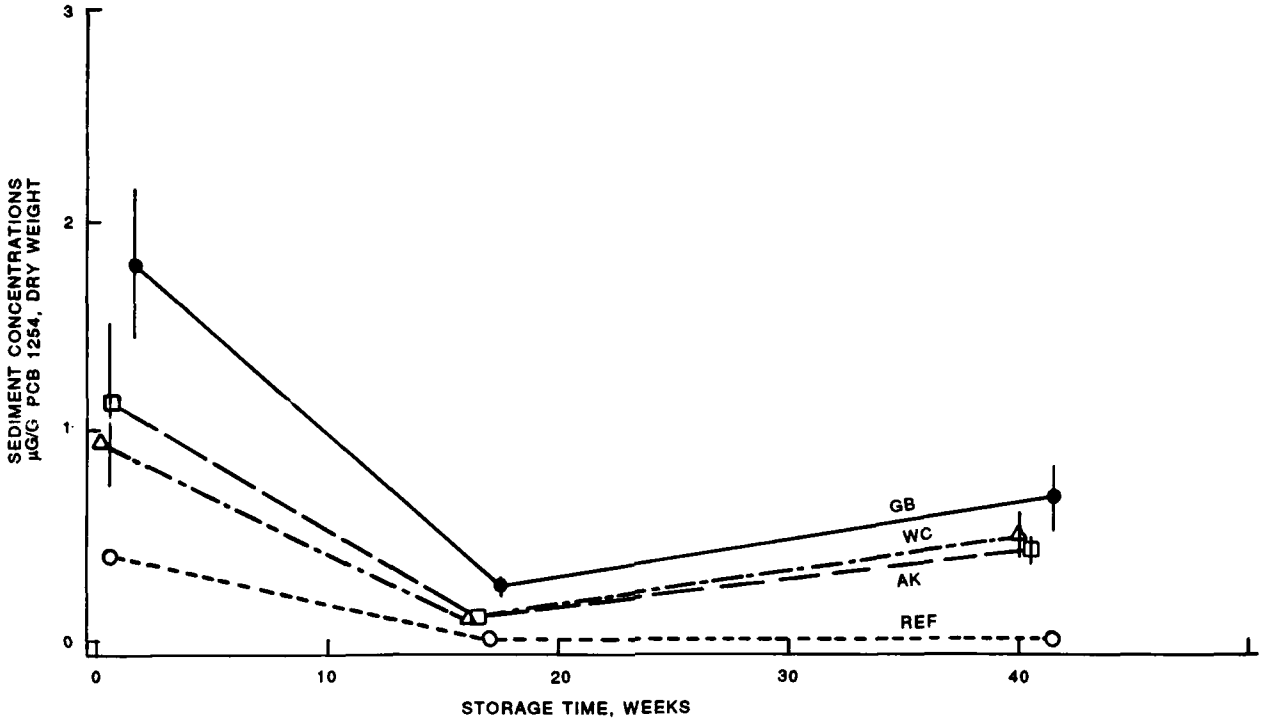


Figure 10. Results of sediment analyses for PCB 1254 (initial and at 16 and 40 weeks)

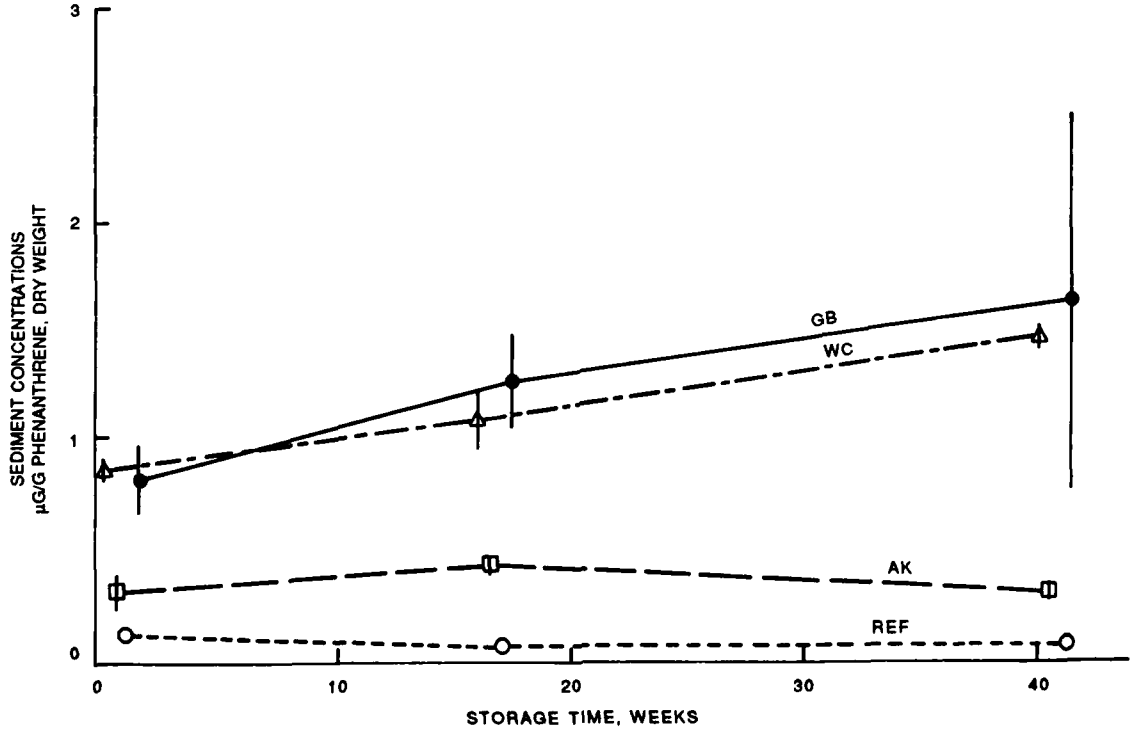


Figure 11. Results of sediment analyses for phenanthrene (initial and at 16 and 40 weeks)

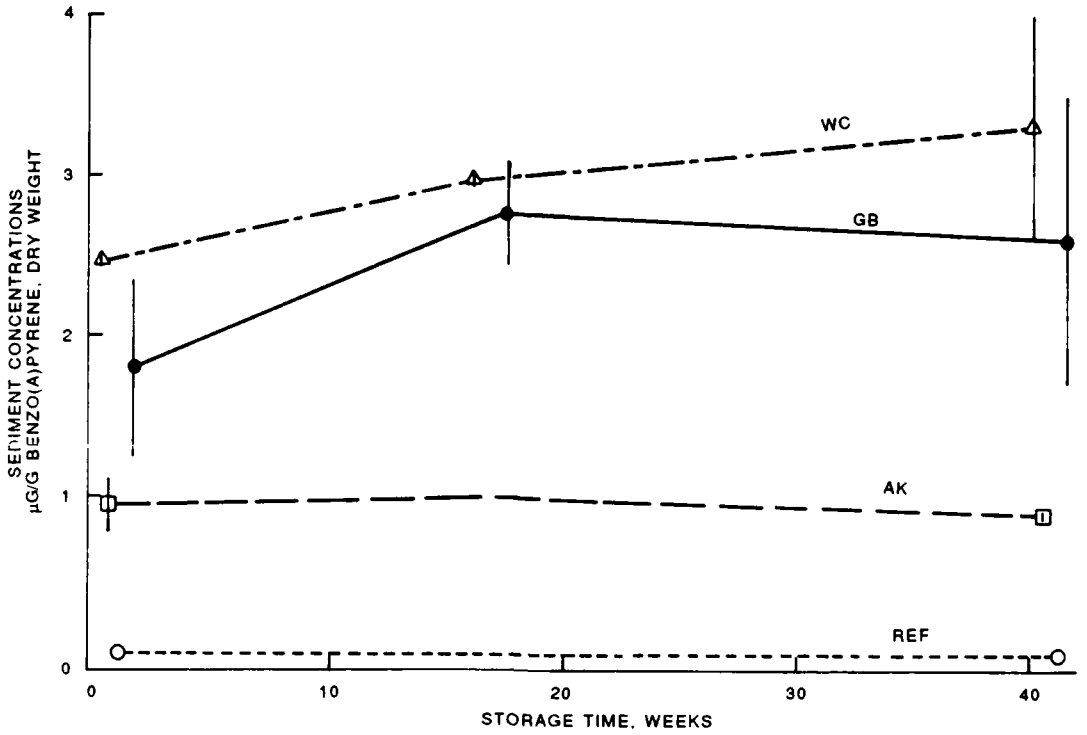


Figure 12. Results of sediment analyses for benzo(a)pyrene (initial and at 16 and 40 weeks)

during 40 weeks of storage. There were a few cases in which significant increases were shown, primarily at 16 weeks, and one case in which a significant decrease was found. After 40 weeks storage, all of the test sediments contained substantial concentrations of PAHs and the Ref sediment continued to contain less than detectable values. One phthalate, bis(2-ethylhexyl), was found in the test sediments and did not change during the storage period.

44. Previous investigations of sediment storage effects have focused on effects on organism survival after exposure to contaminated sediments stored for various times (Dillon 1983; Malueg, Schuytema, and Krawczyk 1986; Tatem 1988). Many other sediment toxicity studies (Nebeker et al. 1984, Swartz et al. 1985, Clark et al. 1987, Plesha et al. 1988) and sediment bioaccumulation studies and reviews (McLeese, Metcalfe, and Pezzack 1980; Neff 1984; Olsen 1984; Seelye and Mac 1984) have been reported but do not specifically examine the question of the effect of sediment storage on test results or sediment chemistry. Most investigators have attempted to perform the biological tests as soon as possible after sediment collection.

45. It is generally agreed that sediments to be used for biological testing should be held at 4° C and that sediments intended solely for bulk

chemical characterization can be frozen and held for a period of months or longer. The American Society for Testing and Materials has published methods for conducting acute aquatic toxicity tests (Method E 729-80) and is in the process of publishing sediment toxicity methods and guidelines for sediment collection, storage, and characterization. None of the above studies, however, discusses data from a series of sediment bioaccumulation tests conducted on sediment held for various times under specific laboratory conditions. No data were found regarding the effects of storage on chemical analyses of sediments held at 4° C for various times.

46. Complete priority pollutant chemistry data for the four test sediments are shown in Table A3. These data may be consulted in relation to the toxicity and bioaccumulation results. Sediment chemistry data can be useful in ranking sediments or for establishing a reason for conducting other tests but cannot, by themselves, be used to predict toxicity or bioaccumulation potential.

PART IV: SUMMARY AND CONCLUSIONS

Summary

47. A reference and three contaminated sediments were obtained from the field, homogenized, and stored at 4° C for 40 weeks. Sediment toxicity and bioaccumulation tests were performed five times, and sediments were chemically analyzed initially (<2 weeks) and at 16 and 40 weeks. Toxicity tests were conducted with *Mysidopsis bahia*. Bioaccumulation tests were performed using the polychaete *Nereis virens*.

Toxicity

48. The mysid toxicity tests showed that survival of Ref-exposed animals was consistently higher than that of mysids exposed to the three test sediments. Data for WC-exposed animals, the sediment shown to be the most toxic initially, showed that this sediment remained significantly toxic to the mysids throughout the 40-week storage period. The other test sediments, GB and AK, were shown to be only moderately toxic compared to WC. They were not significantly toxic at 4 weeks storage but were at 8 weeks, and remained toxic at 16 weeks. These data show that a highly toxic sediment remained toxic during 40 weeks of storage while other similarly contaminated sediments, which were only moderately toxic, increased in toxicity during 16 weeks of storage but were less toxic at 40 weeks.

49. Survival of *N. virens* during 10-day tests was consistent throughout the study period for three of the four sediments. Animals exposed to the Ref and two of the test sediments revealed better than 90-percent survival for most tests. Animals exposed to the WC material, however, revealed increased toxicity at 16 weeks storage compared to previous tests. The test at 40 weeks confirmed that the WC sediments had become more toxic during storage.

Bioaccumulation

50. Tissue analyses of *Nereis* for metals, PCBs, and PAH compounds revealed differences for specific contaminants, but in many cases, similar bioaccumulation results were obtained for each of the tests conducted during the storage period. Contaminants generally not bioaccumulated included Hg and 10 of 17 PAHs. Those contaminants that were bioaccumulated from either GB or WC sediment included Pb, Cd, PCBs, and 7 of 17 PAHs. The PAH compounds most likely to be bioaccumulated included acenaphthene, fluoranthene, pyrene, and chrysene.

51. The PCB data showed bioaccumulation. *Nereis* exposed to the GB sediment accumulated PCBs at all five test times. The PCB data for WC-exposed sandworms were not as conclusive as those for sandworms exposed to GB sediment, possibly due to the relative concentrations of PCBs in these two sediments.

52. In many cases the test animals did not bioaccumulate PAHs. No significant bioaccumulation was shown for many of these organic sediment contaminants, including naphthalene, 2-methylnaphthalene, fluorene, benzo(a)pyrene, and benzo(ghi)perylene. These data indicate that sediment storage had no effect on bioaccumulation results. There were also cases in which bioaccumulation was demonstrated initially (acenaphthene, fluoranthene, pyrene, and chrysene) and shown to occur again in later tests. Animals exposed to GB sediment accumulated acenaphthene and fluoranthene in all five tests. However, bioaccumulation for WC animals was not always demonstrated for many of the PAHs that were bioaccumulated at least three times during the 40-week storage period (fluoranthene, pyrene, and chrysene). Chrysene data showed that animals exposed to GB sediment accumulated chrysene at four of the five test times. However, sandworms exposed to WC sediment accumulated chrysene initially, but not at 4 weeks. Thus, the decision for chrysene was that storage past the initial test (<2 weeks) could result in a change in the bioaccumulation finding.

Sediment chemistry

53. Sediment chemistry data revealed some statistical differences for specific sediment parameters measured initially and at 16 and 40 weeks of storage. The actual effects of these changes on sediment toxicity or bioaccumulation potential are unknown. Thus, a statistical change in the concentration of a few sediment parameters should not be used, without additional biological data, to justify a decision on the effects of sediment storage.

54. The chemistry data for contaminated sediments indicate that oil and grease and COD concentrations tended to decrease during sediment storage while TKN and NH_3-N tended to increase. Statistical analyses showed that some metals decreased during storage, especially in the WC sediment, but the results at 16 weeks were not always consistent with those at 40 weeks. For example, silver at 16 weeks was lower than the initial determination but unchanged, at 40 weeks, compared to initial levels. Mercury in WC sediment increased from initial to 40 weeks storage. Only two metals, arsenic and antimony, revealed significant decreases at either 16 or 40 weeks for all

three sediments. The PCB data show significant decreases; however, much of the data are in the same range as the detection limits. The PCB data suggest an analytical pattern where all of the data at 16 weeks are low in relation to initial. The 40-week data are generally intermediate between the initial and 16-week data. None of the test sediments contained more than approximately 6.0 ppm total PCB. The remainder of the sediment chemistry data show that the DDT compounds and the PAHs did not decrease during sediment storage.

Conclusions

55. The toxicity, bioaccumulation, and sediment chemistry data presented here show that storage of these sediments, for up to 16 or 40 weeks at 4° C, may have an effect on biological and chemical test results. There are cases where the data indicate that a different regulatory decision would be obtained if a sediment was tested after being stored. There are also cases where similar results were obtained for each of five separate biological tests. A clearly toxic sediment remained toxic during 40 weeks of sediment storage. *Nereis* survival in two of three contaminated sediments was consistent for 40 weeks. Contaminants that were bioaccumulated initially continued to be accumulated in subsequent tests. The best examples are lead, PCBs, and three of the PAHs. Many contaminants were not bioaccumulated at any of the test times. Sediment chemistry data indicated that conventional sediment parameters such as organic carbon, COD, and nitrogen were more likely to reveal changes during storage compared to the metals or PAHs. Sediment chemistry data indicated that, for PCB 1254, some loss occurred during storage; however, for the other PCBs, the data were inconsistent.

56. These data do not conclusively show that sediment storage has no effect on biological tests or that storage always affects test results. The data should be used, with other information, to decide how long sediments can be stored prior to conducting initial or additional sediment biological and chemical tests. Although there was some evidence that holding sediments for 16 or even 40 weeks did not result in substantial changes in biological or chemical test results, it is recommended that sediment characterization tests be started as soon as possible after sediment collection. Sediments should be held wet and in full, covered containers, at 4° C after collection and prior to testing.

57. Tests conducted on stored sediments are capable of accurately characterizing sediments. Toxicity data indicate that toxic sediments such as WC can be stored for 40 weeks without significant changes. Other sediments, such as GB and AK, may change during storage and should be tested within 4 weeks even though our data indicate that these sediments generally increased in toxicity during 16 weeks of storage.

58. The bioaccumulation data indicate that sediment storage did result in changes in the bioaccumulation result in many cases, although there were specific cases where *Nereis* exposed to one sediment showed bioaccumulation at all five test times. Also, in numerous cases no bioaccumulation was shown at any of the five test times.

59. It is recommended that all sediments to be tested be characterized by both chemical and biological tests, in case of later questions concerning the results of either method of characterization. It is also recommended that selected sediment subsamples be archived, both frozen and at 4° C, for future reference. Frozen samples may be used for chemical analyses after storage of 0.5 to 1.5 years or longer depending on the contaminant of interest.* Sediment samples held at 4° C may be used for biological tests after storage for up to 8 to 16 weeks, in many cases.

---

* Personal Communication, 1989, Dr. E. Crecelius, Battelle Pacific Northwest Laboratories, Sequim, WA.

REFERENCES

American Public Health Association. 1985. Standard Methods for the Examination of Water and Wastewater, 16th ed., Washington, DC.

Bahnick, D. A., Swenson, W. A., Markee, T. P., Call, D. J., Anderson, C. A., and Morris, R. T. 1981. "Development of Bioassay Procedures for Defining Pollution of Harbor Sediments," EPA-600/S3-81-025, Environmental Research Laboratory, US Environmental Protection Agency, Duluth, MN.

Burton, G. A., and Stemmer, B. L. 1988. "Spiking Method, Sample Storage and Spatial Heterogeneity Effects on Sediment Toxicity to *Daphnia magna*," Abstract, Annual Meeting, Society for Environmental Toxicology and Chemistry, Arlington, VA.

Clark, J. R., Patrick, J. M., Jr., Moore, J. C., and Lores, E. M. 1987. "Waterborne and Sediment-Source Toxicities of Six Organic Chemicals to Grass Shrimp (*Palaemonetes pugio*) and Amphioxus (*Branchiostoma caribaeum*)," Archives of Environmental Contamination and Toxicology, Vol 16, pp 401-407.

Clarke, J. U., and Gibson, A. B. 1987. "Regulatory Identification of Petroleum Hydrocarbons in Dredged Material: Proceedings of a Workshop," Miscellaneous Paper D-87-3, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Dillon, T. 1983. "The Effects of Storage Time and Temperature on Sediment Toxicity," poster presentation, Fourth Annual SETAC Meeting, November 6-9, 1983, Arlington, VA.

Engler, R. M., Wright, T. D., Lee, C. R., and Dillon, T. M. 1989. "Corps of Engineers' Procedures and Policies on Dredging and Dredged Material Disposal (The Federal Standard)," Environmental Effects of Dredging Technical Note EEDP-04-8, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Krahn, M. M., Moore, L. K., Bogar, R. G., Wigren, C. A., Chan, S. L., and Brown, D. W. 1988. "A Rapid High-Performance Liquid Chromatographic Method for Isolating Organic Contaminants from Tissue and Sediment Extracts," Journal of Chromatography, Vol 436, p 161.

LeBlanc, G. A., and Surprenant, D. C. 1985. "A Method of Assessing the Toxicity of Contaminated Freshwater Sediments," Aquatic Toxicology and Hazard Assessment: Seventh Symposium, ASTM STP 854, Philadelphia, PA, pp 269-283.

Malueg, K. W., Schuytema, G. S., Gakstatter, J. H., and Krawczyk, D. F. 1984. "Toxicity of Sediments from Three Metal Contaminated Areas," Environmental Toxicology and Chemistry, Vol 3, pp 279-291.

Malueg, K. W., Schuytema, G. S., and Krawczyk, D. F. 1986. "Effects of Sample Storage on a Copper-Spiked Freshwater Sediment," Environmental Toxicology and Chemistry, Vol 5, pp 245-253.

McLeese, D. W., Metcalfe, C. D., and Pezzack, D. S. 1980. "Uptake of PCBs from Sediment by *Nereis virens* and *Crangon septemspinosa*," Archives of Environmental Contamination and Toxicology, Vol 9, pp 507-518.

Nebeker, A. V., Cairns, M. A., Gakstatter, J. H., Malueg, K. W., Schuytema, G. S., and Krawczyk, D. F. 1984. "Biological Methods for Determining Toxicity of Contaminated Freshwater Sediments to Invertebrates," Environmental Toxicology and Chemistry, Vol 3, pp 617-630.

Neff, J. M. 1984. "Bioaccumulation of Organic Micropollutants from Sediments and Suspended Particulates by Aquatic Animals," Fresenius Z. Anal. Chem., Vol 319, pp 132-136.

Nielson, K. K., and Sanders, R. W. 1983. "Multielement Analysis of Unweighed Biological and Geological Samples Using Backscatter and Fundamental Parameters," Advances in X-Ray Analysis, Vol 26, pp 385-390.

Olsen, L. A. 1984. "Effects of Contaminated Sediment on Fish and Wildlife: Review and Annotated Bibliography," FWS/OBS-82/66, US Fish and Wildlife Service, Washington, DC.

Plesha, P. D., Stein, J. E, Schiewe, M. H., McCain, B. B., and Varanasi, V. 1988. "Toxicity of Marine Sediments Supplemented with Mixtures of Selected Chlorinated and Aromatic Hydrocarbons to the Infaunal Amphipod *Rhepoxynius abronius*," Marine Environmental Research, Vol 25, pp 85-97.

Plumb, R. H., Jr. 1981. "Procedures for Handling and Chemical Analysis of Sediment and Water Samples," Technical Report EPA/CE-81-1, USEPA/USACE Technical Committee on Criteria for Dredged and Fill Material, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Porter, P. S., Ward, R. C., and Bell, H. F. 1988. "The Detection Limit," Environmental Science and Technology, Vol 22, No. 8, pp 856-861.

Prater, B. L., and Hoke, R. A. 1980. "A Method for the Biological and Chemical Evaluation of Sediment Toxicity," Contaminants and Sediments, Vol 1, R. A. Baker, ed., Ann Arbor Science, Ann Arbor, MI.

Seelye, J. G., and Mac, M. J. 1984. "Bioaccumulation of Toxic Substances Associated with Dredging and Dredged Material Disposal: A Literature Review," EPA-905/3-84-005, US Environmental Protection Agency Great Lakes National Program Office, Chicago, IL.

Sokal, R. R., and Rohlf, F. J. 1981. Biometry, W. H. Freeman and Company, San Francisco, CA.

Steel, R. G. D., and Torrie, J. H. 1980. Principles and Procedures of Statistics, McGraw-Hill, New York.

Swartz, R. C., DeBen, W. A., Jones, J. K. P., Lamberson, J. O., and Cole, F. A. 1985. "Phoxocephalid Amphipod Bioassay for Marine Sediment Toxicity," Aquatic Toxicology and Hazard Assessment: Seventh Symposium, ASTM STP 854, Philadelphia, PA, pp 284-307.

Tatem, H. E. 1988. "Use of *Daphnia magna* and *Mysidopsis almyra* to Assess Sediment Toxicity," Water Quality '88 Seminar Proceedings, R. G. Willey, ed., USACE Committee on Water Quality, Washington, DC, pp 269-281.

US Army Engineer District, New York. 1984. "Guidance for Performing Tests on Dredged Material to be Disposed of in Ocean Waters," New York District and USEPA Region 2, New York, NY.

USEPA/USACE Technical Committee on Criteria for Dredged Material. 1978. "Ecological Evaluation of Proposed Discharge of Dredged Material into Ocean Waters; Section 103 Implementation Manual," US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Winer, B. J. 1971. Statistical Principles in Experimental Design, McGraw-Hill, New York.

Table 1a

Effects of Sediment Storage on Mean Survival of Mysidopsis bahia Exposed to Reference or Contaminated Sediment for 120 hr - Statistical Comparisons at Each Time

Sediment	Initial	4 Weeks	8 Weeks	16 Weeks	40 Weeks
REF	9.4 A*	9.2 A	8.4 A	6.6 A	8.4 A
WC	4.0 C	4.6 B	1.0 C	2.2 B	6.4 B
AK	6.6 B	8.6 A	5.2 B	3.4 B	6.4 B
GB	8.4 A	8.4 A	5.6 B	3.6 B	6.2 B
Control**	9.5	7.8	8.0	5.8	7.0

* Each number represents mean survival of five replicates. Replicate data are shown in Appendix A. The Waller-Duncan K-Ratio t-test was used to separate the means. Means in a column (down) followed by the same uppercase letter were not statistically different.

** Controls were held for 120 hr in culture water without sediment.

Table 1b

Effects of Sediment Storage on Mean Survival of Mysidopsis bahia Exposed to Reference or Contaminated Sediment for 120 hr - Statistical Comparisons Over Time

Sediment	Initial	4 Weeks	8 Weeks	16 Weeks	40 Weeks
REF	9.4 a*	9.2 a	8.4 ab	6.6 b	8.4 ab
WC	4.0 bc	4.6 ab	1.0 d	2.2 cd	6.4 a
AK	6.6 b	8.6 a	5.2 c	3.4 d	6.4 bc
GB	8.4 a	8.4 a	5.6 b	3.6 c	6.2 b
Control**	9.5	7.8	8.0	5.8	7.0

* Each number represents mean survival of five replicates. The Waller Duncan K-Ratio t-test was used to separate the means. Means in a row (across) followed by the same lowercase letter were not statistically different.

** Controls were held for 120 hr in culture water without sediment.

Table 2

Effects of Sediment Storage on Mean Survival of Nereis virens Exposed to Four Sediments for 10 Days

Sediment	Initial	4 Weeks	8 Weeks	16 Weeks	40 Weeks
REF	17.8 A c*	18.3 A bc	19.8 A a	19.5 A ab	19.3 A a
WC	18.8 A a	18.3 A a	17.0 A a	9.5 B b	9.5 B b
GB	18.8 A a	19.5 A a	19.5 A a	18.8 A a	18.0 A a
AK	18.5 A a	18.5 A a	19.5 A a	18.0 A a	19.3 A a
Control**	19.3	19.8	19.3	19.8	20.0

* Each number represents mean survival of four replicates each containing 20 sandworms. Replicate data are shown in Appendix A. The Waller-Duncan K-Ratio t-test was used to separate the means. Means in a column (down) followed by the same uppercase letter were not statistically different; means in a row (across) followed by the same lowercase letter were not statistically different. Parametric analysis of variance was used to evaluate the Nereis data.

** Controls were held for 10 days in clean sand.

Table 3

Effects of Sediment Storage on Mean Tissue Concentrations (ppm) for

Nereis virens Exposed to Two Contaminated Sediments Five Times

Parameter	Sediment	Initial	4 Weeks	8 Weeks	16 Weeks	40 Weeks
Metals						
Cd	Ref	0.635 *	0.843	0.565	0.768	0.475
	GB	0.675	0.795	0.603	0.835	0.520 **
	WC	0.735 **	0.893	0.628	0.830 **	0.457
	(Bk)	0.645(0.04)	0.853(0.11)	0.753(0.21)	0.788(0.09)	0.553(0.03)
Pb	Ref	1.313	1.815	1.353	0.768	0.848
	GB	1.638 **	2.500	2.073 **	1.148 **	1.123
	WC	1.695 **	2.145 **	1.910 **	1.560 **	1.303 **
	(Bk)	1.293(0.06)	1.953(0.28)	1.515(0.14)	0.883(0.19)	0.863(0.05)
Hg	Ref	0.102	0.115	0.110	0.247	0.076
	GB	0.102	0.074	0.065	0.223	0.059
	WC	0.094	0.086	0.077	0.257	0.066
	(Bk)	0.101(0.01)	0.153(0.10)	0.165(0.11)	0.262(0.02)	0.100(0.02)
PCBs						
Total PCBs	Ref	0.261	0.187	0.168	0.196	0.334
	GB	0.632 **	0.396 **	0.406 **	0.402 **	0.677 **
	WC	0.364 **	0.288	0.237 **	0.352	0.349
	(Bk)	0.268(0.07)	0.226(0.03)	0.163(0.03)	0.149(0.03)	0.223(0.02)
PAHs						
Naphtha*	Ref	<0.031	<0.029	<0.027	<0.015	0.189
	GB	<0.046	0.041	<0.019	<0.015	<0.050
	WC	<0.013	<0.044	<0.024	0.061	0.218
	(Bk)	<0.031(0.02)	<0.012(0.00)	<0.027(0.01)	<0.015(0.01)	0.238(0.07)
2MNapht	Ref	<0.031	0.022	<0.028	<0.015	<0.016
	GB	<0.046	<0.073	<0.020	<0.015	<0.015
	WC	<0.021	<0.041	<0.041	<0.056	<0.035
	(Bk)	<0.092(0.10)	<0.016(0.01)	<0.024(0.01)	<0.016(0.01)	<0.012(0.00)

(Continued)

Note: See paragraphs 30-37 for definition of abbreviated terms.

* Data (mean of four replicates) are expressed on a microgram per gram (ppm) dry weight basis; tissue levels for GB and WC sandworms were compared statistically to tissue levels in reference animals. The one-tailed t-test was used to identify means that were statistically different. Background (Bk) data are shown (± standard deviation).

** Value was significantly ($P < 0.05$) greater than the Ref value.

Table 3 (Continued)

Parameter	Sediment	Initial	4 Weeks	8 Weeks	16 Weeks	40 Weeks
PAHs (Cont.)						
Acenaphy	Ref	<0.026	0.023	0.049	<0.021	<0.016
	GB	<0.034	<0.031	<0.019	<0.016	<0.016
	WC	<0.014	<0.040	<0.021	0.093	<0.034
	(Bk)	0.043(0.01)	0.033(0.03)	<0.032(0.01)	0.030(0.00)	<0.012(0.00)
Acenaph	Ref	<0.023	<0.015	<0.033	<0.016	<0.014
	GB	0.090 **	0.066 **	0.036 **	0.040 **	0.078 **
	WC	<0.013	<0.033	<0.015	<0.025	<0.032
	(Bk)	<0.043(0.02)	<0.011(0.00)	<0.029(0.03)	<0.017(0.01)	<0.010(0.00)
Fluoren	Ref	<0.025	<0.016	<0.037	<0.018	<0.022
	GB	0.044	<0.029	<0.019	<0.016	<0.035
	WC	<0.014	<0.036	<0.016	<0.052	<0.049
	(Bk)	<0.050(0.03)	<0.012(0.00)	<0.032(0.03)	<0.019(0.01)	<0.016(0.00)
Phenan	Ref	0.034	0.018	<0.053	<0.017	<0.018
	GB	0.083	0.070	<0.023	0.019	0.044 **
	WC	0.026	<0.036	<0.040	<0.054	<0.043
	(Bk)	<0.060(0.05)	<0.012(0.00)	<0.045(0.06)	<0.034(0.03)	0.022(0.01)
Anthra	Ref	0.150	0.050	0.191	0.082	<0.022
	GB	0.160	0.149 **	0.106	0.085	0.063
	WC	0.094	0.152	0.087	0.181	<0.051
	(Bk)	0.111(0.06)	0.077(0.01)	0.077(0.05)	0.087(0.05)	<0.017(0.00)
Fluoran	Ref	<0.030	<0.015	<0.043	<0.018	<0.096
	GB	0.817 **	0.693 **	0.317 **	0.307 **	0.982 **
	WC	0.134 **	0.093 **	0.057	0.078 **	<0.228
	(Bk)	<0.061(0.06)	<0.012(0.00)	<0.039(0.05)	<0.019(0.01)	<0.072(0.01)
Pyrene	Ref	<0.048	0.083	<0.029	0.101	<0.016
	GB	0.739 **	0.621 **	0.353 **	0.339 **	0.930 **
	WC	0.295 **	0.172	0.146 **	0.236	0.358 **
	(Bk)	0.096(0.06)	0.101(0.06)	0.054(0.05)	0.0087(0.01)	<0.012(0.00)
Benzoaan	Ref	<0.041	<0.017	<0.045	<0.019	<0.008
	GB	<0.043	<0.272	<0.027	0.022	0.063 **
	WC	<0.016	0.063 **	<0.019	<0.058	<0.018
	(Bk)	<0.048(0.03)	<0.013(0.00)	<0.026(0.02)	<0.020(0.01)	<0.006(0.00)

(Continued)

Table 3 (Concluded)

Parameter	Sediment	Initial	4 Weeks	8 Weeks	16 Weeks	40 Weeks
PAHs (Cont.)						
Chrysen	Ref	<0.032	0.020	<0.040	<0.022	<0.008
	GB	0.249 **	0.247 **	0.154	0.144 **	0.234 **
	WC	0.103 **	<0.051	0.074 **	0.076 **	0.102 **
	(Bk)	0.061(0.04)	<0.020(0.02)	<0.027(0.01)	0.025(0.01)	<0.006(0.00)
Benzobfl	Ref	<0.036	<0.020	<0.035	<0.021	<0.008
	GB	<0.041	0.107	<0.030	0.030	0.052 **
	WC	<0.017	<0.053	<0.020	<0.061	<0.020
	(Bk)	<0.063(0.05)	<0.019(0.01)	<0.029(0.02)	<0.022(0.01)	<0.007(0.00)
Benzokfl	Ref	<0.037	<0.019	<0.035	<0.054	0.037
	GB	<0.049	<0.077	0.058	<0.019	0.067 **
	WC	0.017	<0.041	0.034	<0.121	0.054
	(Bk)	<0.081(0.09)	<0.020(0.02)	<0.028(0.02)	<0.029(0.02)	0.033(0.02)
Benzoap	Ref	<0.077	<0.030	<0.042	0.039	0.030
	GB	0.244	0.097	0.083	0.045	0.029
	WC	0.032	<0.063	0.037	<0.072	<0.030
	(Bk)	0.150(0.16)	0.047(0.04)	<0.034(0.02)	0.037(0.02)	0.021(0.01)
Ideno123	Ref	<0.085	<0.047	<0.084	<0.087	<0.017
	GB	<0.115	<0.087	<0.055	<0.060	<0.017
	WC	<0.044	<0.100	<0.053	<0.129	<0.035
	(Bk)	<0.082(0.04)	<0.033(0.01)	<0.063(0.04)	<0.046(0.02)	<0.013(0.00)
Dibenzah	Ref	<0.064	<0.033	<0.069	0.056	0.026
	GB	<0.101	0.144	0.100	0.073	0.038
	WC	<0.025	<0.074	<0.052	<0.101	<0.037
	(Bk)	0.082(0.04)	<0.018(0.00)	<0.047(0.03)	0.070(0.04)	<0.018(0.01)
Benzoghi	Ref	<0.050	<0.025	<0.047	0.108	<0.021
	GB	<0.072	<0.121	<0.031	<0.026	<0.021
	WC	<0.020	<0.058	0.067	<0.073	<0.045
	(Bk)	<0.063(0.04)	<0.022(0.01)	<0.037(0.02)	0.034(0.02)	<0.016(0.00)

Table 4

Initial Chemical Analysis Data for Reference and Test Sediments

Parameter	REF	WC	GB	AK
Percent gravel	3.7 ± 0.3	0.2 ± 0.2	0.1 ± 0.1	13.8 ± 9.3
Percent sand	95.8 ± 0.7	11.4 ± 0.1	26.6 ± 0.8	42.2 ± 6.1
Percent silt	0.1 ± 0.0	40.8 ± 2.6	32.0 ± 0.5	21.5 ± 1.3
Percent clay	0.4 ± 0.5	47.6 ± 2.7	41.3 ± 1.2	22.6 ± 2.2
Percent TOC*	0.1 ± 0.0	4.8 ± 0.1	4.1 ± 0.1	3.9 ± 0.6
Percent TVS	1.2 ± 0.0	12.1 ± 0.2	10.7 ± 0.7	7.4 ± 0.9
O & G (ppm)	11.7 ± 5.5	1457 ± 289	1880 ± 380	1790 ± 0
COD	1245 ± 21	70733 ± 907	68267 ± 3499	59057 ± 1712
TKN	55.5 ± 40	1267 ± 58	1133 ± 58	817 ± 458
TP	98.7 ± 9.0	662 ± 77	538 ± 2.7	1096 ± 307
NH_3-N	6.0 ± 1.4	138 ± 48	78.7 ± 7.4	25.3 ± 1.5
Percent Al	2.5 ± 1.2	6.8 ± 0.1	6.5 ± 0.2	6.1 ± 0.1
Percent Fe	0.9 ± 0.3	4.6 ± 0.0	4.5 ± 0.0	3.7 ± 0.2
Metals (ppm)				
Ag	0.03 ± 0.0	5.98 ± 2.2	3.87 ± 1.3	4.88 ± 0.3
As	4.10 ± 0.1	14.07 ± 3.8	14.43 ± 1.4	35.27 ± 2.9
Cd	0.04 ± 0.0	6.00 ± 0.1	13.17 ± 0.2	8.47 ± 0.3
Cr	20 ± 7.1	266 ± 19	296 ± 23	196 ± 14
Cu	5.3 ± 0.1	336 ± 3.6	367 ± 3.8	436 ± 24
Hg	0.03 ± 0.0	2.4 ± 0.1	3.1 ± 0.2	7.1 ± 0.4
Mn	110 ± 71	657 ± 5.5	473 ± 19	339 ± 17
Ni	4.3 ± 0.6	58.7 ± 1.0	75.5 ± 4.4	56.4 ± 6.7
Pb	13 ± 4.4	329 ± 2.3	382 ± 5.1	387 ± 49
Se	1.0 ± 0.0	1.7 ± 0.7	<1.4 ± 0.1	6.2 ± 0.2
Zn	19 ± 5.6	488 ± 3.1	708 ± 14	568 ± 42
Sb	0.3 ± 0.0	4.5 ± 0.5	10.9 ± 1.9	16.2 ± 1.1
Pesticides (ppm)				
Gamma-BHC (lindane)	<0.010	<0.035	<0.040	<0.025
Heptachlor	<0.010	<0.035	<0.040	<0.025
Aldrin	<0.010	<0.035	<0.040	<0.025
Dieldrin	<0.020	<0.070	<0.080	<0.050
4,4-DDE	<0.020	<0.070	<0.080	0.22 ± 0.2
Endrin	<0.020	<0.070	<0.080	<0.050

(Continued)

* Sediment parameters TOC (total organic carbon), TVS (total volatile solids), Al, and Fe are expressed as percentages, dry weight basis. Conventional parameters, O & G (oil and grease), COD (chemical oxygen demand), TKN (total Kjeldahl nitrogen), TP (total phosphorus), and NH_3-N (ammonia nitrogen) are reported on a wet weight basis. Metals, pesticides, PCBs, and PAHs are reported on a dry weight basis.

Table 4 (Concluded)

Parameter	REF	WC	GB	AK
Pesticides (ppm) (Cont.)				
4,4-DDD	<0.020	<0.070	<0.080	0.47 ± 0.4
Endosulfan sulfate	<0.020	<0.070	<0.080	<0.050
4,4-DDT	<0.020	<0.070	<0.080	0.77 ± 0.7
Methoxychlor	<0.020	<0.070	<0.080	<0.050
Chlordane	<0.040	<0.140	<0.160	<0.100
Toxaphene	<2.000	<7.000	<8.000	<5.000
Polychlorinated biphenyls (ppm)				
PCB-1242	<0.430	<1.210	0.87 ± 0.2	0.63 ± 0.4
PCB-1248	<0.430	<1.210	<1.376	<0.840
PCB-1254	<0.430	0.96 ± 0.1	1.80 ± 0.6	1.13 ± 0.7
PCB-1260	<0.430	<1.210	1.46 ± 0.2	1.05 ± 0.7
Polycyclic aromatic hydrocarbons (ppm)				
Naphthalene	<0.140	0.29 ± 0.2	0.39 ± 0.0	0.28 ± 0.0
2-Methylnaphthalene	<0.073	0.16 ± 0.1	<0.24 ± 0.0	0.17 ± 0.1
Acenaphthylene	<0.008	0.52 ± 0.1	0.31 ± 0.5	0.28 ± 0.3
Acenaphthene	<0.048	<0.14 ± 0.0	0.30 ± 0.3	0.15 ± 0.1
Fluorene	<0.049	0.17 ± 0.1	0.29 ± 0.3	0.15 ± 0.1
Phenanthrene	<0.071	0.85 ± 0.1	0.80 ± 0.3	0.28 ± 0.1
Anthracene	<0.038	0.40 ± 0.0	0.56 ± 0.1	0.26 ± 0.2
Fluoranthene	<0.150	2.10 ± 0	3.20 ± 1.5	2.33 ± 2.0
Pyrene	<0.140	3.20 ± 0.2	3.83 ± 1.8	2.77 ± 1.5
Benzo(a)anthracene	<0.110	1.97 ± 0.1	2.43 ± 0.7	1.34 ± 0.7
Chrysene	<0.027	2.10 ± 0.2	2.33 ± 0.9	1.30 ± 0.8
Benzo(b)fluoranthene	<0.042	1.73 ± 0.2	1.50 ± 0.4	0.96 ± 0.6
Benzo(k)fluoranthene	<0.180	1.63 ± 0.2	1.17 ± 0.5	0.86 ± 0.7
Benzo(a)pyrene	<0.018	2.50 ± 0	1.80 ± 1.0	0.94 ± 0.3
Indeno(123cd)pyrene	<0.073	0.67 ± 0.4	0.45 ± 0.4	0.63 ± 0.4
Dibenzo(ah)anthracene	<0.086	<0.24 ± 0.0	0.28 ± 0.0	0.43 ± 0.3
Benzo(ghi)perylene	<0.078	0.57 ± 0.3	0.48 ± 0.4	0.61 ± 0.4
Total PAH (17)	--	19.2	20.4	13.7
Phthalate esters				
Bis(2-ethylhexyl) phthalate	<0.165	8.7 ± 1.14	31.67 ± 6.35	27.67 ± 9.5
Dibenzofuran	<0.017 ± 0.0	<0.20 ± 0.0	<0.27 ± 0.13	0.297 ± 0.3

Table 5

Chemical Analysis Data for Sediments Stored for 16 Weeks

Parameter	REF	WC	GB	AK
Percent TOC*	0.06 ± 0.01	4.68 ± 0.08	4.03 ± 0.14	3.69 ± 0.70
Percent TVS	0.54 ± 0.31	14.40 ± 1.22	13.21 ± 0.29	11.47 ± 0.36
O & G (ppm)	<5.0 ± 0.0	1703 ± 172	2130 ± 141	1947 ± 247
COD	3205 ± 2638	58567 ± 2371	52667 ± 4316	56100 ± 7451
TKN	50 ± 14.1	1333 ± 57.7	1167 ± 57.7	936.7 ± 46.2
TP	56.0 ± 1.8	412 ± 18.5	330 ± 40.9	723.3 ± 96.8
NH_3-N	<1.0 ± 0.0	66.3 ± 11.9	39.0 ± 8.2	4.5 ± 5.6
Percent Fe	1.17 ± 0.01	4.41 ± 0.10	4.17 ± 0.04	3.61 ± 0.07
Metals (ppm)				
Ag	0.05 ± 0.0	3.13 ± 0.31	2.99 ± 0.43	4.16 ± 0.37
As	5.10 ± 1.84	18.57 ± 3.25	19.37 ± 1.88	39.47 ± 2.21
Cd	0.08 ± 0.04	6.22 ± 0.50	13.36 ± 0.67	9.10 ± 0.56
Cr	42.50 ± 2.12	250 ± 9.3	293 ± 16.4	189 ± 11.0
Cu	6.70 ± 2.40	340 ± 7.21	361 ± 23.7	448 ± 32.0
Hg	0.12 ± 0.12	2.65 ± 0.10	3.14 ± 0.16	7.09 ± 1.13
Mn	169 ± 23.3	645 ± 2.08	456 ± 3.61	348 ± 21.1
Ni	5.05 ± 0.21	57.5 ± 1.69	75.7 ± 11.0	56.6 ± 3.70
Pb	11.1 ± 1.63	322 ± 3.79	367 ± 9.85	377 ± 65.8
Se	<0.78 ± 0.00	1.20 ± 0.17	1.05 ± 0.06	5.74 ± 0.34
Zn	26.6 ± 0.42	481 ± 10.5	706 ± 5.51	569 ± 56.2
Sb	<0.18 ± 0.00	2.06 ± 1.19	4.78 ± 0.46	5.68 ± 1.08
Pesticides (ppm)				
4,4-DDE	<0.0005 ± 0	0.0037 ± 0.001	0.006 ± 0.001	0.0173 ± 0.004
4,4-DDD	<0.0005 ± 0	0.0107 ± 0.003	0.021 ± 0.004	0.1133 ± 0.046
4,4-DDT	<0.0005 ± 0	<0.004 ± 0.001	<0.006 ± 0.001	0.1327 ± 0.132
Polychlorinated biphenyls (ppm)				
PCB-1242	<0.005 ± 0.0	<0.05 ± 0.0	<0.05 ± 0.0	<0.037 ± 0.006
PCB-1248	<0.005 ± 0.0	0.120 ± 0.03	0.367 ± 0.07	0.110 ± 0.020
PCB-1254	0.002 ± 0.0	0.103 ± 0.03	0.260 ± 0.07	0.113 ± 0.021
PCB-1260	0.003 ± 0.0	0.123 ± 0.04	0.253 ± 0.06	0.090 ± 0.027
Total PCB (4)	0.015	0.396	0.930	0.350

(Continued)

* Sediment parameters TOC (total organic carbon), TVS (total volatile solids), Al, and Fe are expressed as percentages, dry weight basis. Conventional parameters, O & G (oil and grease), COD (chemical oxygen demand), TKN (total Kjeldahl nitrogen), TP (total phosphorus), and NH_3-N (ammonia nitrogen) are reported on a wet weight basis. Metals, pesticides, PCBs, and PAHs are reported on a dry weight basis.

Table 5 (Concluded)

Parameter	REF	WC	GB	AK
Polycyclic aromatic hydrocarbons (ppm)				
Naphthalene	<0.017 ± 0.0	<0.200 ± 0.0	<0.273 ± 0.13	<0.133 ± 0.20
2-Methylnaphthalene	<0.017 ± 0.0	0.115 ± 0.07	<0.247 ± 0.16	<0.110 ± 0.03
Acenaphthylene	<0.017 ± 0.0	0.437 ± 0.10	0.473 ± 0.07	<0.150 ± 0.05
Acenaphthene	<0.017 ± 0.0	0.116 ± 0.04	0.340 ± 0.04	1.120 ± 1.39
Fluorene	<0.017 ± 0.0	0.160 ± 0.04	0.347 ± 0.04	0.970 ± 1.17
Phenanthrene	<0.012 ± 0.0	1.070 ± 0.23	1.253 ± 0.37	0.400 ± 0.04
Anthracene	<0.017 ± 0.0	0.637 ± 0.10	1.236 ± 0.46	1.747 ± 2.47
Fluoranthene	<0.012 ± 0.0	2.600 ± 0.27	5.533 ± 2.16	1.650 ± 0.50
Pyrene	<0.013 ± 0.0	3.367 ± 0.42	5.233 ± 1.71	2.050 ± 0.21
Benzo(a)anthracene	<0.017 ± 0.0	2.100 ± 0.17	2.263 ± 2.03	1.095 ± 0.15
Chrysene	<0.017 ± 0.0	2.567 ± 0.25	3.533 ± 0.95	1.200 ± 0.14
Benzo(b)fluoranthene	<0.017 ± 0.0	--	--	--
Benzo(k)fluoranthene	<0.017 ± 0.0	3.733 ± 0.45	4.000 ± 1.14	1.550 ± 0.07
Benzo(a)pyrene	<0.017 ± 0.0	2.967 ± 0.06	2.767 ± 0.55	1.000 ± 0.00
Indeno(123cd)pyrene	<0.017 ± 0.0	1.933 ± 0.21	2.000 ± 0.17	2.556 ± 3.24
Dibenzo(ah)anthracene	<0.017 ± 0.0	0.787 ± 0.06	0.900 ± 0.27	0.943 ± 1.26
Benzo(ghi)perylene	<0.017 ± 0.0	1.433 ± 0.06	1.600 ± 0.30	2.453 ± 3.25
Total PAH (17)	<0.017	24.22	32.00	19.13
Phthalate esters				
Bis(2-ethylhexyl) phthalate	<0.039 ± 0.01	8.233 ± 0.86	20.00 ± 3.00	18.33 ± 6.1
Dibenzofuran	<0.017 ± 0.0	<0.200 ± 0.0	<0.273 ± 0.13	0.297 ± 0.30

Table 6

Chemical Analysis Data for Sediments Stored for 40 Weeks

Parameter	REF	WC	GB	AK
Percent TOC *	1.40	3.83 ± 0.48	3.49 ± 0.10	3.53 ± 0.34
Percent TVS	2.83	13.25 ± 0.21	11.90 ± 0.14	10.45 ± 0.35
O & G (ppm)	23	845 ± 199	1175 ± 205	927 ± 74.9
COD	2070	29850 ± 9687	33625 ± 6117	25680 ± 1245
TKN	39	3500 ± 282	2750 ± 70.7	2800 ± 1556
TP	48	442 ± 37	348 ± 33	806 ± 51
NH_3-N	4	410 ± 0	195 ± 7.1	83 ± 4.2
Percent Fe	1.11	4.32 ± 0.07	4.13 ± 0.13	3.86 ± 0.07
Metals (ppm)				
Ag	0.03	6.58 ± 1.31	6.26 ± 0.11	5.81 ± 0.12
As	5.10	6.60 ± 1.84	<4.10 ± 0.0	28.0 ± 2.83
Cd	0.06	5.71 ± 0.08	13.42 ± 0.12	10.1 ± 2.78
Cr	45.00	245 ± 14.9	283 ± 3.54	200 ± 17.7
Cu	17.00	309 ± 4.95	345 ± 17.7	469 ± 11.3
Hg	0.06	2.71 ± 0.09	3.25 ± 0.18	8.80 ± 1.08
Mn	129.0	627 ± 0	444 ± 2.83	377 ± 7.07
Ni	6.00	59.5 ± 2.12	69.5 ± 3.54	62.0 ± 5.66
Pb	18.00	314 ± 4.24	369 ± 2.83	439 ± 46.7
Sb	<0.11	1.55 ± 0.68	3.76 ± 0.16	6.06 ± 0.67
Se	<0.80	<1.0 ± 0	<1.0 ± 0	5.90 ± 0.42
Zn	46.00	461 ± 8.49	650 ± 25.5	634 ± 42.4
Pesticides (ppm)				
4,4-DDE	<0.001	0.054 ± 0.01	0.064 ± 0.02	0.140 ± 0.01
4,4-DDD	<0.001	0.055 ± 0.01	0.073 ± 0.03	0.265 ± 0.02
4,4-DDT	<0.001	<0.038 ± 0.03	<0.013 ± 0.004	0.49 ± 0.21
Polychlorinated biphenyls (ppm)				
PCB-1242	<0.01	<0.02 ± 0	<0.02 ± 0	<0.30 ± 0.14
PCB-1248	<0.01	0.45 ± 0.10	0.78 ± 0.21	0.52 ± 0.10
PCB-1254	<0.01	0.51 ± 0.15	0.68 ± 0.21	0.44 ± 0.09
PCB-1260	<0.01	<0.02 ± 0	<0.02 ± 0	<0.30 ± 0.14
Total PCB (4)	<0.01	1.00	1.50	1.56

(Continued)

* Sediment parameters TOC (total organic carbon), TVS (total volatile solids), Al, and Fe are expressed as percentages, dry weight basis. Conventional parameters, O & G (oil and grease), COD (chemical oxygen demand), TKN (total Kjeldahl nitrogen), TP (total phosphorus), and NH_3-N (ammonia nitrogen) are reported on a wet weight basis. Metals, pesticides, PCBs, and PAHs are reported on a dry weight basis.

Table 6 (Concluded)

Parameter	REF	WC	GB	AK
Polycyclic aromatic hydrocarbons (ppm)				
Naphthalene	<0.012	0.235 ± 0.08	0.370 ± 0.18	<0.14 ± 0.08
2-Methylnaphthalene	<0.012	0.205 ± 0.08	0.225 ± 0.16	<0.14 ± 0.08
Acenaphthylene	<0.012	1.185 ± 0.30	0.960 ± 0.62	0.22 ± 0.09
Acenaphthene	<0.012	0.255 ± 0.08	0.565 ± 0.09	0.114 ± 0.12
Fluorene	<0.012	0.515 ± 0.12	0.475 ± 0.28	<0.14 ± 0.08
Phenanthrene	<0.012	1.450 ± 0.07	1.620 ± 1.25	0.27 ± 0.06
Anthracene	<0.012	0.860 ± 0.34	1.210 ± 0.55	0.26 ± 0.06
Fluoranthene	<0.012	3.650 ± 0.78	5.550 ± 3.32	1.95 ± 0.07
Pyrene	<0.012	4.700 ± 1.56	6.450 ± 3.47	2.35 ± 0.07
Benzo(a)anthracene	<0.012	3.200 ± 0.99	3.450 ± 1.91	1.15 ± 0.07
Chrysene	<0.012	2.500 ± 0.07	3.050 ± 1.49	1.10 ± 0.14
Benzo(b)fluoranthene	<0.012	--	--	--
Benzo(k)fluoranthene	<0.012	5.200 ± 1.56	4.000 ± 1.84	1.50 ± 0.14
Benzo(a)pyrene	<0.012	3.300 ± 0.99	2.600 ± 1.27	0.89 ± 0.03
Indeno(123cd)pyrene	<0.012	2.000 ± 0.71	1.450 ± 0.64	0.565 ± 0.02
Dibenzo(ah)anthracene	<0.012	0.985 ± 0.30	0.780 ± 0.31	0.38 ± 0.17
Benzo(ghi)perylene	<0.012	2.200 ± 0.85	1.490 ± 0.72	0.65 ± 0.04
Total PAH (17)	<0.012	32.44	34.25	11.82
Phthalate esters				
Bis(2-ethylhexyl) phthalate	0.024	9.75 ± 3.18	16.8 ± 14.4	17.00 ± 2.83
Dibenzofuran	<0.012	<0.11 ± 0.01	0.20 ± 0.10	<0.14 ± 0.08

Table 7

Statistical Analyses of Sediment Chemistry Data -

Conventional Parameters

Parameter	Initial	16 Weeks	40 Weeks	Significant Difference
		Site WC		
Percent TOC	4.76 A*	4.68 A	3.83 A	No change
Percent TVS	12.10 A	14.40 A	13.25 A	No change
O & G	1456.67 A	1703.33 A	845.00 B	- 40 weeks
COD	70733.33 A	58566.67 B	29850.00 C	- 16, 40
TKN	1266.67 B	1333.33 AB	3500.00 A	+ 40
TP	662.33 A	412.33 B	442.00 B	- 16
NH3	137.67 B	66.33 C	410.00 A	+ 40
		Site GB		
Percent TOC	4.12 A	4.03 A	3.49 B	- 40 weeks
Percent TVS	10.66 A	13.21 A	11.90 A	No change
O & G	1880.00 A	2130.00 A	1175.00 B	- 40
COD	68266.67 A	52666.67 B	33625.00 C	- 16, 40
TKN	1133.33 B	1166.67 B	2750.00 A	+ 40
TP	538.00 A	330.00 B	347.50 B	- 16
NH3	78.67 B	39.00 C	195.00 A	+ 40
		Site AK		
Percent TOC	3.93 A	3.69 A	3.53 A	No change
Percent TVS	7.36 B	11.47 A	10.45 A	+ 16 weeks
O & G	1790.00 A	1946.67 A	927.00 B	- 40
COD	59056.67 A	56100.00 A	25680.00 B	- 40
TKN	816.67 A	936.67 A	2800.00 A	No change
TP	1095.67 A	723.33 A	806.00 A	No change
NH3	25.33 B	4.53 C	83.00 A	+ 40
		Site REF		
Percent TOC	0.11 A	0.06 B	1.4	
Percent TVS	1.18 A	0.54 B	2.8	
O & G	11.65 A	<5.00 A	23.0	
COD	1245.00 A	3205.00 A	2070.0	
TKN	55.50 A	50.00 A	39.0	
TP	98.65 A	55.95 B	48.0	
NH3	6.00 A	<1.00 B	4.0	

* Each number represents the mean of either three (initial and 16 weeks) or two (40 weeks) samples. The Waller-Duncan K-Ratio t-test was used to separate the means. Means in a row (across) followed by the same uppercase letter were not statistically different at the 0.05 level.

Table 8

Statistical Analyses of Sediment Chemistry Data - Metals

Parameter, ppm	Initial	16 Weeks	40 Weeks	Significant Difference
		Site WC		
Ag	5.98 A*	3.13 B	6.58 A	- 16 weeks
As	14.07 AB	18.57 A	6.60 B	- 40
Cd	6.00 A	6.22 A	5.71 A	No change
Cr	265.67 A	250.33 A	244.50 A	No change
Cu	336.00 A	340.00 A	308.50 B	- 40
Fe (%)	4.57 A	4.41 AB	4.32 B	- 40
Hg	2.44 B	2.65 AB	2.71 A	+ 40
Mn	657.33 A	644.67 B	627.00 C	- 16, 40
Ni	58.73 A	57.53 A	59.50 A	No change
Pb	328.67 A	322.33 AB	314.00 B	- 40
Sb	4.46 A	2.06 B	1.55 B	- 16
Se	1.68 A	1.19 A	<1.00 A	No change
Zn	487.67 A	481.33 A	461.00 B	- 40
		Site GB		
Ag	3.87 A	2.98 A	6.26 A	No change
As	14.43 B	19.34 A	4.10 C	- 40 weeks
Cd	13.17 A	13.36 A	13.42 A	No change
Cr	296.33 A	292.67 A	282.50 A	No change
Cu	366.67 A	361.33 A	344.50 A	No change
Fe (%)	4.46 A	4.17 B	4.13 B	- 16
Hg	3.09 A	3.14 A	3.25 A	No change
Mn	472.67 A	456.00 A	444.00 A	No change
Ni	75.50 A	75.67 A	69.50 A	No change
Pb	381.67 A	367.00 A	369.00 A	No change
Sb	10.89 A	4.78 B	3.76 C	- 16, 40
Se	1.36 A	1.05 B	<1.00 B	- 16
Zn	708.00 A	705.67 A	650.00 B	- 40
		Site AK		
Ag	4.88 B	4.16 B	5.81 A	+ 40 weeks
As	35.27 A	39.47 A	28.00 B	- 40
Cd	8.47 A	9.10 A	10.09 A	No change
Cr	196.33 A	189.33 A	200.50 A	
Cu	436.00 A	448.00 A	469.00 A	
Fe (%)	3.74 A	3.61 A	3.86 A	
Hg	7.07 A	7.09 A	8.79 A	
Mn	339.00 A	348.33 A	377.00 A	

(Continued)

* Each number represents the mean of either three (initial and 16 weeks) or two (40 weeks) analyses. The Waller-Duncan K-Ratio t-test was used to separate the means. Means in a row (across) followed by the same uppercase letter were not statistically different at the 0.05 level.

Table 8 (Concluded)

Parameter, ppm	Initial	16 Weeks	40 Weeks	Significant Difference
Ni	56.40 A	56.0 A	62.00 A	No change
Pb	387.33 A	377.00 A	439.00 A	No change
Sb	16.17 A	5.67 B	6.06 B	- 16
Se	6.15 A	5.7 A	5.00 A	No change
Zn	568.33 A	569.00 A	634.00 A	No change
		Site REF		
Ag	0.03 A	0.05 A	0.03	
As	4.10 A	5.10 A	5.10	
Cd	0.04 A	0.08 A	0.06	
Cr	20.00 A	42.00 A	45.00	
Cu	5.25 A	6.70 A	17.00	
Fe (%)	0.88 A	1.17 A	1.11	
Hg	0.04 A	0.12 A	0.06	
Mn	110.00 A	168.50 A	129.00	
Ni	4.30 A	5.05 A	6.00	
Pb	13.30 A	11.05 A	18.00	
Sb	0.30 A	<0.18 A	<0.11	
Se	0.97 A	<0.78 A	<0.80	
Zn	18.55 B	26.60 A	46.00	

Table 9

Statistical Analyses of Sediment Chemistry Data - PCBs and DDTs

Parameter	Initial	16 Weeks	40 Weeks	Significant Difference
		Site WC		
1242	<1.210*	<0.050	<0.020	No change
1248	<1.210 A	0.120 C	0.450 B	+ 40 weeks
1254	0.960 A	0.103 C	0.505 B	- 16, 40
1260	<1.210	0.123	<0.020	No change
		Site GB		
1242	0.867 A	<0.050 B	<0.020 C	- 16, 40 weeks
1248	<1.376 A	0.367 C	0.775 B	+ 40
1254	1.800 A	0.260 C	0.680 B	- 16, 40
1260	1.467 A	0.253 B	<0.020 C	- 16, 40
		Site AK		
1242	0.633 A	<0.037 B	<0.300 AB	- 16 weeks
1248	<0.840 A	0.110 C	0.520 B	+ 40
1254	1.133 A	0.113 C	0.435 B	- 16, 40
1260	1.047 A	0.090 C	<0.300 B	- 16, 40
DDE	0.230 A	0.017 B	0.140 AB	- 16
DDD	0.483 A	0.113 A	0.265 A	No change
DDT	0.783 A	0.133 A	0.490 A	No change
		Site REF		
1242	<0.40 A	<0.005 B	<0.01	
1248	<0.40 A	<0.005 B	<0.010	
1254	<0.40 A	0.002 B	<0.010	
1260	<0.40 A	0.002 B	<0.010	
DDE	<0.02 A	<0.001 B	<0.001	
DDT	<0.02 A	<0.001 B	<0.001	

* Each number represents the mean of either three (initial and 16 weeks) or two (40 weeks) analyses. The Waller-Duncan K-Ratio t-test was used to separate the means. Means in a row (across) followed by the same uppercase letter were not statistically different at the 0.05 level.

Table 10

Statistical Analyses of Sediment Chemistry Data - PAHs

Parameter	Initial	16 Weeks	40 Weeks	Significant Difference
		Site WC		
Naphthalene	0.293 A*	<0.200 A	0.235 A	No change
2MNaphthalene	0.157 A	0.115 A	0.205 A	
Acenaphthylene	0.523 A	0.437 A	1.185 A	
Acenaphthene	<0.137 A	0.116 A	0.255 A	
Fluorene	0.170 A	0.160 A	0.515 A	
Phenanthrene	0.847 A	1.070 A	1.450 A	
Anthracene	0.403 B	0.637 A	0.860 A	+ 16 weeks
Fluoranthene	2.100 C	2.600 B	3.650 A	+ 16, 40
Pyrene	3.200 A	3.367 A	4.700 A	No change
Benzo(a)anthracene	1.967 A	2.100 A	3.200 A	No change
Chrysene	2.100 A	2.567 A	2.500 A	No change
Benzo(k)fluoranthene	1.633 A	3.733 A	5.200 A	No change
Benzo(a)pyrene	2.467 A	2.967 A	3.300 A	No change
Indeno(123cd)pyrene	0.663 B	1.933 A	2.000 A	+ 16
Dibenzo(ah)anthracene	<0.243 A	0.787 A	0.985 A	No change
Benzo(ghi)perylene	0.570 A	1.433 A	2.200 A	No change
Total PAHs	19.24 B	24.22 A	32.44 A	
Bis(2ethex)phthalate	8.867 A	8.233 A	9.750 A	No change
		Site GB		
Naphthalene	0.390 A	<0.273 A	0.370 A	No change
2MNaphthalene	<0.237 A	<0.247 A	0.225 A	
Acenaphthylene	0.310 A	0.473 A	0.960 A	
Acenaphthene	0.303 A	0.340 A	0.565 A	
Fluorene	0.300 A	0.347 A	0.475 A	
Phenanthrene	0.800 A	1.253 A	1.620 A	
Anthracene	0.560 A	1.236 A	1.210 A	
Fluoranthene	3.200 A	5.533 A	5.550 A	
Pyrene	3.833 A	5.233 A	6.450 A	
Benzo(a)anthracene	2.433 A	2.263 A	3.450 A	
Chrysene	2.333 A	3.533 A	3.050 A	
Benzo(k)fluoranthene	1.170 A	4.000 A	4.000 A	
Benzo(a)pyrene	1.800 A	2.767 A	2.600 A	
Indeno(123cd)pyrene	0.450 B	2.000 A	1.450 A	+ 16 weeks
Dibenzo(ah)anthracene	0.277 B	0.900 A	0.780 AB	+ 16
Benzo(ghi)perylene	0.480 A	1.600 A	1.490 A	No change
Total PAHs	20.36 A	31.998 A	34.25 A	
Bis(2ethex)phthalate	31.667 A	20.000 A	16.800 A	No change

* Each number represents the mean of either three (initial and 16 weeks) or two (40 weeks) analyses. The Waller-Duncan K-Ratio t-test was used to separate the means. Means in a row (across) followed by the same uppercase letter were not statistically different at the 0.05 level.

Table 10 (Concluded)

Parameter	Initial	16 Weeks	40 Weeks	Significant Difference
		Site AK		
Naphthalene	0.273 A *	<0.133 B	<0.142 B	- 16 weeks
2MNaphthalene	0.173 A	<0.110 A	<0.142 A	No change
Acenaphthylene	0.282 A	<0.150 A	0.220 A	
Acenaphthene	0.144 A	1.120 A	0.114 A	
Fluorene	0.146 A	0.970 A	<0.142 A	
Phenanthrene	0.277 A	0.400 A	0.270 A	
Anthracene	0.263 A	1.747 A	0.260 A	
Fluoranthene	2.333 A	1.650 A	1.950 A	
Pyrene	2.733 A	2.050 A	2.350 A	
Benzo(a)anthracene	1.337 A	1.095 A	1.150 A	
Chrysene	1.303 A	1.200 A	1.100 A	
Benzo(k)fluoranthene	0.857 A	1.550 A	1.500 A	
Benzo(a)pyrene	0.943 A	1.000 A	0.890 A	
Indeno(123cd)pyrene	0.633 A	2.557 A	0.565 A	
Dibenzo(ah)anthracene	0.433 A	0.943 A	0.380 A	
Benzo(ghi)perylene	0.613 A	2.453 A	0.650 A	
Total PAHs	13.74 B	19.13 A	11.82 A	
Bis(2ethex)phthalate	27.67 A	18.33 A	17.00 A	No change
		Site REF		
Naphthalene	<0.135 A	<0.017 B	<0.012	
2MNaphthalene	<0.071 A	<0.017 B	<0.012	
Acenaphthylene	<0.008 B	<0.017 A	<0.012	
Acenaphthene	<0.047 A	<0.017 B	<0.012	
Fluorene	<0.048 A	<0.017 B	<0.012	
Phenanthrene	<0.069 A	<0.012 B	<0.012	
Anthracene	<0.037 A	<0.017 B	<0.012	
Fluoranthene	<0.145 A	<0.012 B	<0.012	
Pyrene	<0.135 A	<0.013 B	<0.012	
Benzo(a)anthracene	<0.105 A	<0.017 B	<0.012	
Chrysene	<0.026 A	<0.017 B	<0.012	
Benzo(k)fluoranthene	<0.175 A	<0.017 B	<0.012	
Benzo(a)pyrene	<0.018 A	<0.017 A	<0.012	
Indeno(123cd)pyrene	<0.071 A	<0.017 B	<0.012	
Dibenzo(ah)anthracene	<0.083 A	<0.017 B	<0.012	
Benzo(ghi)perylene	<0.076 A	<0.017 B	<0.012	
Bis(2ethex)phthalate	<0.165 A	0.039 A	0.024	

APPENDIX A: REPLICATE DATA AND STATISTICAL METHODS

Table A1

Replicate and Mean Survival of Mysids Exposed at 120 hr

Sediment	Initial	4 Weeks	8 Weeks	16 Weeks	40 Weeks
Reference	10	8	9	9	8
(REF)	9	9	8	5	8
	10	10	7	8	9
	9	9	8	8	9
	9	10	10	3	8
	9.4(0.25)A +	9.2(0.37)A *	8.4(0.51)A +	6.6(1.1)A *	8.4(0.25)A *
	+ a	a	ab	b	ab
Westchester	5	3	0	3	8
(WC)	2	4	1	4	6
	6	4	0	1	6
	1	6	1	2	6
	6	6	3	1	6
	4.0(1.1)C +	4.6(0.60)B *	1.0(0.55)C +	2.2(0.58)B *	6.4(0.40)B *
	* bc	ab	d	cd	a
Arthur Kill	5	9	6	4	6
(AK)	7	7	8	3	7
	7	8	3	4	7
	7	10	4	3	6
	7	9	5	3	6
	6.6(0.40)B +	8.6(0.51)A *	5.2(0.86)B +	3.4(0.25)B *	6.4(0.25)B *
	+ b	a	c	d	bc
Gowanus Bay	8	10	5	2	5
(GB)	10	7	6	4	5
	7	6	5	4	7
	9	10	7	2	5
	8	9	5	6	9
	8.4(0.51)A +	8.4(0.81)A *	5.6(0.40)B +	3.6(0.75)B *	6.2(0.80)B *
	* a	a	b	c	b
Controls	9	7	8	4	5
(CON)	9	9	9	4	7
	10	9	7	7	9
	10	6	8	6	7
	-	8	8	8	-
	9.5(0.26)	7.8(0.58)	8.0(0.32)	5.8(0.80)	7.0(0.73)

Note: The Waller-Duncan K-Ratio t-test was used to separate the means. Standard errors of the mean are shown in parentheses. An asterisk indicates a parametric ANOVA; + symbol indicates a nonparametric ANOVA. Uppercase letters show comparisons of the four sediments at each of five times; lowercase letters show comparisons over time for each sediment.

Table A2

Replicate and Mean Survival of Nereis Exposed at 10 Days

Sediment	Initial	4 Weeks	8 Weeks	16 Weeks	40 Weeks
REF	17	18	20	20	20
	18	18	20	20	19
	17	18	19	20	20
	19	19	20	18	18
	17.8(0.5)Ac	18.3(0.3)Abc	19.8(0.3)Aa	19.5(0.5)Aab	19.3(0.5)Aa
WC	20	18	16	10	12
	19	19	14	10	10
	17	18	19	11	8
	19	18	19	7	8
	18.8(0.7)Aa	18.3(0.3)Aa	17.0(1.3)Aa	9.5(0.9)Bb	9.5(1.0)Bb
GB	18	20	20	17	18
	20	19	20	19	16
	18	19	20	20	20
	19	20	18	19	18
	18.8(0.5)Aa	19.5(0.3)Aa	19.5(0.5)Aa	18.8(0.7)Aa	18.0(0.8)Aa
AK	19	19	20	20	20
	20	20	19	16	18
	16	17	20	17	20
	19	18	19	19	19
	18.5(0.9)Aa	18.5(0.7)Aa	19.5(0.3)Aa	18.0(0.9)Aa	19.3(0.5)Aa
CON	20	19	17	19	-
	19	20	20	20	-
	18	20	20	20	20
	20	20	20	20	20
	19.3(0.5)	19.8(0.3)	19.3(0.8)	19.8(0.3)	20.0(0.0)

Note: The Waller-Duncan K-Ratio t-test was used to separate the means. Standard errors of the mean are shown in parentheses. Statistical analyses were parametric. Controls were held for 10 days in clean sand.

Table A3

Priority Pollutant Data for REF and Test Sediments

Parameter	REF	WC	GB	AK
Sediment, percent*				
Gravel	3.7 ± 0.3	0.2 ± 0.2	0.1 ± 0.1	13.8 ± 9.3
Sand	95.8 ± 0.7	11.4 ± 0.1	26.6 ± 0.8	42.2 ± 6.1
Silt	0.1 ± 0.0	40.8 ± 2.6	32.0 ± 0.5	21.5 ± 1.3
Clay	0.4 ± 0.5	47.6 ± 2.7	41.3 ± 1.2	22.6 ± 2.2
TOC	0.1 ± 0.0	4.8 ± 0.1	4.1 ± 0.1	3.9 ± 0.6
TVS	1.2 ± 0.0	12.1 ± 0.2	10.7 ± 0.7	7.4 ± 0.9
Miscellaneous**				
O & G (ppm)	11.7 ± 5.5	1457 ± 289	1880 ± 380	1790 ± 0
COD	1245 ± 21	70733 ± 907	68267 ± 3499	59057 ± 1712
TKN	55.5 ± 40	1267 ± 58	1133 ± 58	817 ± 458
TP	98.7 ± 9.0	662 ± 77	538 ± 2.7	1096 ± 307
NH_3-N	6.0 ± 1.4	138 ± 48	78.7 ± 7.4	25.3 ± 1.5
Al*	2.5 ± 1.2	6.8 ± 0.1	6.5 ± 0.2	6.1 ± 0.1
Fe*	0.9 ± 0.3	4.6 ± 0.0	4.5 ± 0.0	3.7 ± 0.2
Metals, ppm†				
Ag	0.03 ± 0.0	5.98 ± 2.2	3.87 ± 1.3	4.88 ± 0.3
As	4.10 ± 0.1	14.07 ± 3.8	14.43 ± 1.4	35.27 ± 2.9
Be	0.70 ± 0.1	2.53 ± 0.1	2.71 ± 0.1	2.23 ± 0.2
Cd	0.04 ± 0.0	6.00 ± 0.1	13.17 ± 0.2	8.47 ± 0.3
Cr	20 ± 7.1	266 ± 19	296 ± 23	196 ± 14
Cu	5.3 ± 0.1	336 ± 3.6	367 ± 3.8	436 ± 24
Hg	0.03 ± 0.0	2.4 ± 0.1	3.1 ± 0.2	7.1 ± 0.4
Mn	110 ± 71	657 ± 5.5	473 ± 19	339 ± 17
Ni	4.3 ± 0.6	58.7 ± 1.0	75.5 ± 4.4	56.4 ± 6.7
Pb	13 ± 4.4	329 ± 2.3	382 ± 5.1	387 ± 49
Se	1.0 ± 0.0	1.7 ± 0.7	<1.4 ± 0.1	6.2 ± 0.2
Zn	19 ± 5.6	488 ± 3.1	708 ± 14	568 ± 42
Sb	0.3 ± 0.0	4.5 ± 0.5	10.9 ± 1.9	16.2 ± 1.1
Tl	<0.1 ± 0.0	0.8 ± 0.0	0.7 ± 0.1	0.5 ± 0.1

(Continued)

* Sediment parameters, total organic carbon, total volatile solids, aluminum and iron are expressed as percentage, dry weight basis.

** Parameters oil and grease, chemical oxygen demand, total Kjeldahl nitrogen, total phosphorus, and ammonia nitrogen are reported on a wet weight basis.

† Metals, pesticides, PCBs, and PAHs are reported on a dry weight basis.

(Sheet 1 of 4)

Table A3 (Continued)

Parameter	REF	WC	GB	AK
Pesticides, ppm†				
Alpha-BHC	<0.010	<0.035	<0.040	<0.025
Beta-BHC	<0.010	<0.035	<0.040	<0.025
Delta-BHC	<0.010	<0.035	<0.040	<0.025
Gamma-BHC (lindane)	<0.010	<0.035	<0.040	<0.025
Heptachlor	<0.010	<0.035	<0.040	<0.025
Aldrin	<0.010	<0.035	<0.040	<0.025
Heptachlor epoxide	<0.010	<0.035	<0.040	<0.025
Endosulfan 1	<0.010	<0.035	<0.040	<0.025
Dieldrin	<0.020	<0.070	<0.080	<0.050
4,4-DDE	<0.020	<0.070	<0.080	0.22 ± 0.2
Endrin	<0.020	<0.070	<0.080	<0.050
Endosulfan 11	<0.020	<0.070	<0.080	<0.050
4,4-DDD	<0.020	<0.070	<0.080	0.47 ± 0.4
Endosulfan sulfate	<0.020	<0.070	<0.080	<0.050
4,4-DDT	<0.020	<0.070	<0.080	0.77 ± 0.7
Methoxychlor	<0.020	<0.070	<0.080	<0.050
Endrin ketone	<0.020	<0.070	<0.080	<0.050
Chlordane	<0.040	<0.140	<0.160	<0.100
Toxaphene	<2.000	<7.000	<8.000	<5.000
Polychlorinated biphenyls, ppm†				
PCB-1242	<0.430	<1.210	0.87 ± 0.2	0.63 ± 0.4
PCB-1248	<0.430	<1.210	<1.376	<0.840
PCB-1254	<0.430	0.96 ± 0.1	1.80 ± 0.6	1.13 ± 0.7
PCB-1260	<0.430	<1.210	1.46 ± 0.2	1.05 ± 0.7
Polycyclic aromatic hydrocarbons, ppm†				
Naphthalene	<0.140	0.29 ± 0.2	0.39 ± 0.0	0.28 ± 0.0
2-Methylnaphthalene	<0.073	0.16 ± 0.1	<0.24 ± 0.0	0.17 ± 0.1
Acenaphthylene	<0.008	0.52 ± 0.1	0.31 ± 0.5	0.28 ± 0.3
Acenaphthene	<0.048	<0.14 ± 0.0	0.30 ± 0.3	0.15 ± 0.1
Fluorene	<0.049	0.17 ± 0.1	0.29 ± 0.3	0.15 ± 0.1
Phenanthrene	<0.071	0.85 ± 0.1	0.80 ± 0.3	0.28 ± 0.1
Anthracene	<0.038	0.40 ± 0.0	0.56 ± 0.1	0.26 ± 0.2
Fluoranthene	<0.150	2.10 ± 0	3.20 ± 1.5	2.33 ± 2.0
Pyrene	<0.140	3.20 ± 0.2	3.83 ± 1.8	2.77 ± 1.5
Benzo(a)anthracene	<0.110	1.97 ± 0.1	2.43 ± 0.7	1.34 ± 0.7
Chrysene	<0.027	2.10 ± 0.2	2.33 ± 0.9	1.30 ± 0.8
Benzo(b)fluoranthene	<0.042	1.73 ± 0.2	1.50 ± 0.4	0.96 ± 0.6
Benzo(k)fluoranthene	<0.180	1.63 ± 0.2	1.17 ± 0.5	0.86 ± 0.7
Benzo(a)pyrene	<0.018	2.50 ± 0	1.80 ± 1.0	0.94 ± 0.3
Indeno(123cd)pyrene	<0.073	0.67 ± 0.4	0.45 ± 0.4	0.63 ± 0.4
Dibenzo(ah)anthracene	<0.086	<0.24 ± 0.0	0.28 ± 0.0	0.43 ± 0.3
Benzo(ghi)perylene	<0.078	0.57 ± 0.3	0.48 ± 0.4	0.61 ± 0.4
Total PAH (17)	--	19.2	20.4	13.7

Table A3 (Continued)

Parameter	REF	WC	GB	AK
Halogenated aliphatics and ethers				
Hexachloroethane	<0.064	<0.190	<0.220	<0.130
Hexachlorobutadiene	<0.074	<0.220	<0.250	<0.150
Hexachlorocyclopentadiene	<0.070	<0.210	<0.240	<0.140
Bis(2-chloroisopropyl)ether	<0.105	<0.310	<0.360	<0.220
Bis(2-chloroethyl)ether	<0.036	<0.110	<0.120	<0.073
4-chlorophenyl-ether	<0.059	<0.170	<0.200	<0.120
4-bromophenyl-ether	<0.053	<0.160	<0.180	<0.110
Bis(2-chloroethoxy)methane	<0.098	<0.290	<0.330	<0.200
Nitrobenzene	<0.044	<0.130	<0.150	<0.089
1,2-dichlorobenzene	<0.010	<0.029	<0.032	<0.020
1,3-dichlorobenzene	<0.015	<0.042	<0.048	<0.029
1,4-dichlorobenzene	<0.037	<0.110	<0.120	<0.075
1,2-4-trichlorobenzene	<0.075	<0.220	<0.250	<0.160
Hexachlorobenzene	<0.071	<0.210	<0.240	<0.150
2,4-dinitrotoluene	<0.040	<0.120	<0.130	<0.080
2,6-dinitrotoluene	<0.109	<0.320	<0.370	<0.230
Phenols				
Phenol	<0.033	<0.095	<0.110	<0.067
2-chlorophenol	<0.040	<0.120	<0.130	<0.081
2-methylphenol	<0.049	<0.140	<0.170	<0.100
4-methylphenol	<0.025	<0.071	<0.081	<0.050
2-nitrophenol	<0.130	<0.390	<0.430	<0.270
2,4-dimethylphenol	<0.115	<0.340	<0.390	<0.240
2,4-dichlorophenol	<0.135	<0.400	<0.460	<0.280
4-chloro-3-methylphenol	<0.076	<0.230	<0.260	<0.160
2,4,6-trichlorophenol	<0.025	<0.072	<0.082	<0.051
2,4,5-trichlorophenol	<0.030	<0.087	<0.098	<0.061
2,4-dinitrophenol	<0.260	<0.760	<0.870	<0.530
4-nitrophenol	<0.083	<0.240	<0.280	<0.170
4,6-dinitro-2-methylphenol	<0.270	<0.790	<0.890	<0.550
Pentachlorophenol	<0.053	<0.160	<0.180	<0.110
Phthalate esters				
Dimethylphthalate	<0.040	<0.120	<0.130	<0.080
Diethylphthalate	<0.032	<0.094	<0.110	<0.066
Di-n-butylphthalate	<0.063	<0.190	<0.210	<0.130
Di-n-octylphthalate	<0.135	<0.390	0.480	0.410
Butylbenzylphthalate	<0.165	<0.480	<0.550	<0.310
Bis(2-ethylhexyl)phthalate	<0.165	8.7 ± 1.14	31.67 ± 6.35	27.67 ± 9.50

(Continued)

Table A3 (Concluded)

Parameter	REF	WC	GB	AK
Nitrosamines and miscellaneous compounds				
Di-n-propylnitrosamine	<0.064	<0.190	<0.220	<0.130
Benzyl alcohol	<0.043	<0.130	<0.150	<0.087
Benzidine (benzoic acid)	<0.135	<0.400	<0.460	<0.280
3,3'-Dichlorobenzidine	<0.067	<0.200	<0.220	<0.140
N-diphenylnitrosamine	<0.130	<0.390	<0.440	<0.270
4-Chloroaniline	<0.071	<0.210	<0.240	<0.150
2-Nitroaniline	<0.130	<0.390	<0.430	<0.270
3-Nitroaniline	<0.076	<0.230	<0.260	<0.160
4-Nitroaniline	<0.155	<0.440	<0.510	<0.310
2-Chloronaphthalene	<0.006	<0.018	<0.020	<0.012
Dibenzofuran	<0.068	<0.200	<0.230	<0.140
Isophorone	<0.098	<0.290	<0.330	<0.200